MICHIGAN GEOLOGICAL AND BIOLOGICAL SURVEY

Publication 3
Geological Series 2

THE IRON RIVER IRON-BEARING DISTRICT OF MICHIGAN

BY

R. C. ALLEN

PUBLISHED AS A PART OF THE ANNUAL REPORT OF THE BOARD OF GEOLOGICAL AND BIOLOGICAL SURVEY FOR 1910

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1910

ERRATA.

Page 13, line 31, read *are* instead of *is*.

Page 21, line 2, read *northeast toward the southwest* for *northwest toward the southeast.*

Page 89, line 14, read *40* instead of *400*.

Page 112, line 26, read *similar* instead of *familiar*.

Page 118, line 9, read *east* for *west*.

Page 138, fig. 16, read *Stambaugh Hill* for *Sheridan Hill*.

Page 139, line 23, read *transpiration* instead of *exhalation*.

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BOARD OF GEOLOGICAL AND BIOLOGICAL SURVEY.

1910.

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LETTER OF TRANSMITTAL.

To the Honorable the Board of Geological and Biological Survey of the State of Michigan:

Governor Fred M. Warner, President.
Hon. D. M. Ferry, Jr., Vice President.
Hon. L. L. Wright, Secretary.

Gentlemen:—I beg to present herewith as a part of the report for 1910 of the Board of Geological and Biological Survey, Publication No. 3, a report on the geology of the Iron River Iron-Bearing District of Michigan.

Very respectfully,
R. C. ALLEN,
Director.

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THE IRON RIVER IRON BEARING DISTRICT OF MICHIGAN.

BY R. C. ALLEN.

CHAPTER I.

INTRODUCTION.

Field work in the Iron River district was begun by the writer in July and continued to October, 1909. During the spring and summer of 1910 frequent visits were made for the purpose of obtaining additional geological information which is constantly accumulating as new explorations are undertaken.

No earlier attempt had been made to map the geology of this district in any detail. The published literature is limited to brief mention here and there in reports of the Michigan and the United States Geological Surveys and to reports of geologists and mining engineers for commercial interests. Professor W. S. Bayley in 1901 made a cursory examination of the southern part of the area including the vicinity of Iron River and Stambaugh. The results of Prof. Bayley's examination were not published. Through the courtesy of the United States Geological Survey the writer was furnished a copy of Prof. Bayley's notes.

That published information regarding the geology of this district is so meagre is due to the deep cover of glacial drift through which the underlying formations project only in widely separated outcrops. Over wide areas there are no rock exposures. The meagre data afforded by rock exposures has in late years been supplemented by a large amount of underground exploratory work undertaken in search for iron ore.

As far as possible all geological facts are indicated by appropriate color or symbol on the general map of the district (Plate 1). The large scale of this map, 2 in. to the mile, and the subdivision of

the sections into quarters and sixteenths are features which should appeal to land owners and explorers for iron ore. While the sheet is not too large for convenient use it is large enough to be used as a base on which to record new information which is rapidly accumulating as drilling progresses. The location of rock outcrops were ascertained in many cases by pacing to the nearest known section, quarter, or sixteenth corner while others, especially those in the producing area, were transferred from plats furnished by mining companies, as were also the location of shafts, pits, and drill holes. Where information warrants, formation boundaries have been indicated. It is regretted that information is as yet far from adequate for drawing the limits of the iron formation belts. In constructing the map, the writer has tried to delineate faithfully and accurately known facts of geology and has resisted the temptation to project extensions of iron formation belts very far beyond known occurrences on basis of inferred structure. However, such extensions are dealt with in the text of the report.

Much of the credit for any value which this report may have is due to the cooperation of the mining companies and land owners of the district. The writer was given free access to drill records, drill cores, mine plats, and underground workings of the mines, and in many cases the facilities of the mine offices were tendered him. But for the active assistance rendered by the mine operators and explorers this work could not have been done at all. The writer is indebted to practically every company, superintendent, engineer and mine captain in the district, not only for information freely given but for personal courtesy and kindnesses that have made the work a pleasure. Thanks are due to Messrs. I. N. Woodworth, O. R. Hamilton, Lowe Whiting, Zebina McColman, G. L. Bottsford, William Connibear and W. H. Selden for personal favors and assistance, and special indebtedness is acknowledged to Mr. Leigh Townsend and Parnell G. McKenna for assistance in preparation of the illustrations, to Mr. Ray Willoughby and I. D. Scott who acted as field assistants, Mr. Willoughby during July and August and Mr. Scott in September, 1909, and to Mr. O. W. Wheelwright who made detailed plats of special areas.

Lansing, Michigan, Nov. 15, 1910. R. C. ALLEN.

HISTORY AND DEVELOPMENT.

The first discovery of iron ore in the Iron River district is accredited to Mr. Harvey Mellen, a United States land surveyor. The field notes of Mr. Mellen's under date of August 8, 1851, describe the occurrence of an "outcrop of iron ore five feet high" on the west face of Stambaugh Hill, 52 chains north of the southwest corner of Section 36, T. 43 N., R. 35 W., and this outcrop was recorded on the original United States Land Survey plat of the township. While the occurrence of ore was thus early made known* mining did not begin until 31 years later, when Mr. Mellen's discovery became the site of the Iron River mine. The opening of the district dates from the fall of 1882 when the Chicago and Northwestern railroad reached Iron River with a spur from Iron River Junction, now Stager, and shipments began almost simultaneously from the Iron River and Nanaimo mines. In anticipation of the building of the railroad there came an influx of settlers, and the villages of Iron River and Stambaugh grew rapidly during the summers preceding the arrival of the railroad.

The history of the mining industry in this district is divided naturally into three periods; the first embraces the years 1882 to 1893, the second 1894 to 1898, and the third from 1899 to date.

During the years 1882 to 1893 inclusive the only important shippers were the Iron River and Nanaimo mines. The Beta was opened in 1886, the Sheridan in 1889 and the Hiawatha in 1893. The total shipments from these mines, including 2,092 tons from a prospect known as the Selden, was only 1,136,444 tons of which the Sheridan is credited with 56,813 tons and the Nanaimo 12,566 tons. The largest output for a single year was 180,340 tons in 1889.

In view of the rapid developments of recent years one is lead to inquire why the opening of the district was not followed by a more rapid expansion in the mining industry, such as characterized the earlier years of the Menominee, Penokee-Gogebic and Vermilion ranges which were opened about the same time, the Menominee in 1877, and Vermilion in 1883, and the Penokee-Gogebic in 1884. The explanation is not difficult to find but is involved in part in each of several factors, a brief consideration of which may be of some interest.

The most important of these is undoubtedly the non Bessemer

*Iron ore was first discovered in the Lake Superior region in 1844 near the site of the old Jackson mine at Negaunce.

character of the Iron River ores. The decade preceding the opening of the Iron River district witnessed the movement of the center of iron manufacture from the Lehigh Valley to the head waters of the Ohio, and a gradual but rapid substitution of steel for iron. With the development of the Bessemer process of steel making came an increased demand for Bessemer ores. Only under exceptional conditions of the iron trade in these early years was there any real demand for Lake Superior high phosphorous ores such as occur in the Iron River district, while ordinarily these ores were with difficulty salable at all. Consequently there was little incentive for investment of capital in exploration for new deposits, especially when it was correctly infered, as later developments have shown, that such deposits if found would be of non Bessemer character.

With the opening of Bessemer ore deposits on the Vermilion range in 1883 and the Penokee-Gogebic range in 1884 mining capital was promptly attracted to these more promising districts to the disadvantage of the Iron River and neighboring areas. But aside from the non Bessemer character of the ore there are adverse natural conditions confronting the explorer in the Iron River district which do not exist to the same degree in other Michigan ranges. These for many years have stood in the way of mining development. The rocks are buried beneath thick deposits of glacial drift. Rock exposures are so few and scattered that in themselves they offer insufficient data for guidance in either exploration or accurate geologic mapping. The rocks can be reached in most places only by drilling or deep pitting. Yet had the early discoveries been of more promising character there is no doubt that active development would have followed despite the natural difficulties involved in exploring a heavily wooded and deeply drift-covered region.

That the extent and character of the ore-bearing fields remained for so many years unknown is not, however, altogether due to the foregoing causes. Titles to a large acreage of lands were for many years in litigation. This was an outgrowth of conflicts between homesteaders who had "squatted" on lands which previously had been claimed under various railroad and canal grants. The history of these disputes regarding land titles has no present interest beyond the fact that during their progress the lands involved were eliminated from the market and to that extent exercised a deterrent effect on mining development.

A fourth and least factor which operated to retard de-

velopment is found in a certain notion held by many of the earlier prospectors and explorers regarding the origin of the iron ores. Since the earlier known ore deposits were in the narrow valley of Iron River, by a curious but not surprising inference the idea became prevalent in the minds of many that the occurrence of ore was in some unexplainable manner genetically related to the valley and was not to be searched for elsewhere in this district. Even to the present day a valley or "draw" presents alluring prospects to many explorers as is shown by the location of several of the more recent operations. The idea is not without *some* scietific basis as will be discussed in a later chapter.

During this period, with the exception of a prospect in Sec. 26, T. 43 N., R. 34 W., now known as the Chicagon mine, operations were confined to the valley of Iron River in the vicinity of the villages of Iron River and Stambaugh, where the Iron River and Nanaimo mines, with a few struggling prospects, kept the industry alive up to the financial depression of 1893.

An attempt at local smelting was made at the Nanaimo mine in 1884. In this year an organization known as the Iron River Furnace company built a charcoal furnace with a capacity of seventy tons and a row of charcoal kilns north of the mine on the opposite side of the river. The plant was never operated successfully.

Of the five years from 1893 to 1898, inclusive, there is little to record of the mining industry at Iron River. A glance at the table of productions on page ... tells the story. These were gloomy times. Those districts having the less desirable ores to market are always the hardest hit and slowest to recover in times of general depression in the iron and steel trade and mining at Iron River received a death blow in the panic of 1893. Thereafter until the gradual resumption of mining beginning in 1899 the villages of Iron River and Stambaugh found practically their only support in the agricultural and lumbering industries. With the panic of 1893 came the opening of the great Mesabi range. The Mesabi district presented a matchless field for the explorer and the mining capital of the Lake Superior region was promptly absorbed in the opening of the new district. The discovery of the enormous high grade Bessemer deposits of the Mesabi, which can be mined at a cost per ton far below that for the old ranges, together with the low prices following the panic, brought about a condition much to the disadvantage of the old districts. However, the softness of the Mesabi

ores made them less desirable in furnace practice than the harder old range Bessemer ores and it was in great measure the demand of the furnacemen for hard ores to mix with the soft Mesabi ores that sustained the market for the old range Bessemer product, while the Crystal Falls and Iron River districts with nothing to sell but non Bessemer ore were for a time all but entirely eliminated from the mining industry. But the steady and rapid increase in the consumption of pig iron since 1897, and the heavy and ever increasing draughts on deposits of high grade Bessemer ores has finally brought the more phosphoric ores permanently into the market. With each succeeding year the mines find it increasingly more difficult to meet the demand of the furnaces for low phosphorous ore. The result has been a gradual development of open hearth steel manufacture at the expense of the Bessemer process and a strengthening of the market for the more phosphoric ores.

A market once firmly established, the devolpment of the Iron River district was assured and has gone steadily forward. The last decade, forming the third period under discussion, has been one of expansion. The annual shipments with the exception of that for 1902 have each year shown an increase over the preceding year and have grown from 5,009 tons in 1898 to 1,151,871 tons in 1909. Active development began in 1896 when the Mastodon Iron Company of Crystal Falls began exploring the property now known as the Dober mine. Later this mine came into the hands of the Oliver Iron Mining Company by whom it has been developed into one of the largest producers of the district. The Baltic was explored by the Verona Mining company in 1900 and shipments began in the following year. In 1900 the Hiawatha was added to the list of shippers and the Caspian in 1902. The following year operations were resumed at the old Iron River mine which had been idle since 1892, and a year later the Youngs mine was added to the number of producers. The James and Brule mines made first shipments in 1907, the Berkshire and Zimmerman in 1908, while last year saw two more producers enter the list, the Fogarty with a shipment of 77,356 tons and the Baker with 45,002 tons. There were in all 11 producing mines in 1909 and in addition a number of promising explorations, some of which will undoubtedly become shippers in the near future. During the last decade, and especially in the past four years, much exploratory work has been done increasing in proportion our knowledge of the character and extent of the ore-

bearing strata. From the narrow valley of Iron River, explorations have been pushed outward in all directions, but chiefly to the north, east and southeast of Iron River.

The future of the Iron River district never looked brighter than at the close of 1909. The shipments for the year were approximately double those for each of the preceding three years, while the amount of exploratory work accomplished and projected was unprecedented in the history of the range. There are at present 15 different companies conducting mining and exploratory operations and several others are contemplating entering the field. There is appended a table of productions covering the years from 1882, when first shipments were made, to the end of 1909.

TABLE OF SHIPMENT OF IRON ORE

Mines.	1882.	1883.	1884.	1885.	1886.	1887.	1888.
Nanaimo	2,480	29,221	37,620	....	5,400	30,460	5,744
Iron River (Riverton)	29,115	100,369	52,583	55,693	78,591	{ 39,493 83,018	} 110,000
Selden	....	....	....	....	790	1,302	....
Beta	....	....	....	....	1,585	1,226	....
Sheridan	....	....	....	....	....	....	....
Hiawatha	....	....	....	....	....	....	....
Dober (Riverton)	....	....	....	....	....	....	....
Baltic	....	....	....	....	....	....	....
Caspian	....	....	....	....	....	....	....
Youngs	....	....	....	....	....	....	....
James	....	....	....	....	....	....	....
Brule, Cratham No. 1 and No. 2	....	....	....	....	....	....	....
Berkshire	....	....	....	....	....	....	....
Zimmerman	....	....	....	....	....	....	....
Baker	....	....	....	....	....	....	....
Fogarty	....	....	....	....	....	....	....
Total	31,595	129,590	90,203	55,693	86,366	155,499	115,744

Mines.	1897.	1898.	1899.	1900.	1901.	1902.
Nanaimo	....	....	....	....	....	....
Iron River (Riverton)	....	....	....	....	....	....
Selden	....	....	....	....	....	....
Beta	....	....	....	....	....	....
Sheridan	146	....	31,104	8,063	....	....
Hiawatha	....	....	....	11,098	20,355	74,596
Dober (Riverton)	....	5,009	13,242	120,207	119,860	215,850
Baltic	....	....	....	....	17,326	64,664
Caspian	....	....	....	....	....	....
Youngs	....	....	....	....	....	....
James	....	....	....	....	....	....
Brule, Chatham No. 18, No. 2	....	....	....	....	....	....
Berkshire	....	....	....	....	....	....
Zimmerman	....	....	....	....	....	....
Baker	....	....	....	....	....	....
Fogarty	....	....	....	....	....	....
Total	146	5,009	44,346	139,278	157,541	355,110

FROM THE IRON RIVER DISTRICT, 1882-1909.

1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.
....	3,441	13,200	....	....	....	....	....
179,238	155,458	59,345	1,176	....	....	....	....
....	....	....	....	....	....	....	....
....	....	1,400	....	....	....	....	....
1,102	595	7,137	45,745	2,234	....	16,754	3,419
....	....	....	....	1,683	....	1,201	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
180,340	159,494	81,082	46,921	3,917	....	17,955	3,419

1903.	1904.	1905.	1906.	1907.	1908.	1909.	Total.
....	9,086	91,238	91,792	53,778	305	....	373,765
....	....	....	....	....	....	....	944,079
....	....	....	....	....	....	....	2,092
....	....	....	....	....	....	....	4,211
....	....	....	....	....	....	....	116,299
53,828	38,288	9,704	20	....	138,190	136,740	485,613
97,633	81,543	82,611	161,704	90,358	47,073	171,200	1,206,290
123,236	151,114	133,246	186,495	189,119	129,037	174,220	1,168,457
2,088	4,242	10,248	80,875	138,867	102,628	189,023	527,971
....	....	10,926	47,583	92,632	70,094	154,150	375,385
....	....	....	....	2,360	59,760	90,851	152,971
....	....	....	....	14,883	45,826	68,730	129,439
....	....	....	....	....	3,440	34,296	37,736
....	....	....	....	....	1,832	10,303	12,135
....	....	....	....	....	....	45,002	45,002
....	....	....	....	....	....	77,356	77,356
276,785	284,273	336,973	568,469	581,997	598,185	1,151,871	....

CHAPTER II.

PHYSIOGRAPHY.

GENERAL FEATURES.

The topography of the Iron River district is of glacial origin slightly modified by preglacial forms and by postglacial erosion. In general the area presents a series of hills or parallel chains of hills elongated in a direction about S. 20° W. which is the direction of ice movement as recorded on striated and grooved rock surfaces in the southwestern and northern parts of the area. The ridges are separated by corresponding hollows which hold swamps and lakes connected by creeks forming the minor drainage courses. The major drainage is independent of the natural northeast-southwest "grain" of the country, for the larger streams, the Brule, Iron, and Paint rivers cross diagonally the general southwest trend of the hills and valleys. The Paint river in the northern part of the district follows, in general, the strike of the underlying rocks, outcrops being comparatively numerous along its course. The same may be said of the Brule river in the southern part of the district. Both of these streams may follow modified preglacial courses. This is, however, certainly not true of the Iron river for this stream is known to cross at least two well defined drift-filled, preglacial valleys which fall toward the northeast nearly at right angles to the course of the Iron. These valleys are separated by a rock ridge which protrudes through the drift in Stambaugh hill on which is built the village of Stambaugh. (See Plate 1).

In contrast to the independence of the major streams the minor drainage is controlled absolutely by the topography of the drift mantle which may be readily inferred from a study of the topographic map. Frequently the lakes occupying depressions between the ridges are, like them, elongated in a northeast-southwest direction. The best examples are Stanley and Iron lakes; others are Minnie, Chicagon, and Trout lakes occupying parts of the same depression in the eastern part of the area. Most of the lakes are

drained by streams, but some, as Bennan, Snipe, and Scott lakes have no outlets.

The combination of elongated ridges and corresponding depressions forms a distinctly drumloid type of topography. However, there are but few typical drumlins. The most nearly perfect example occurs just north of Iron River village, crossing the south line of Sec. 23, T. 43 N., R. 35 W. A terminal moraine formed by the Langlade lobe (Weidman) of the Wisconsin ice sheet occurs not far to the south in Wisconsin, following a general northwesterly course at a high angle to the trend of the drumloid hills of this area. This is a characteristic relation between drumlins and terminal moraine found elsewhere, notably in New York and Southern Wisconsin.

Thickness of Glacial Drift.—The thickness of the drift varies from nothing up to above 300 feet. It is of course thinnest along the depressions and major drainage courses where the underlying rocks are frequently exposed and on the average thickest in the hills between them. In some instances postglacial and preglacial valleys coincide in general trend and carry greater thicknesses of drift than bordering hills. This is true of the preglacial valley extending diagonally northeast through Sec. 1, T. 42 N., R. 35 W. and Sections 31 and 29, T. 43 N., R. 34 W. (See map Pl. 1.)

While the elevation of many of the hills is accounted for by the relatively great thicknesses of drift under them there is abundant evidence that the preglacial topography of this region was more rugged and presented greater vertical range between hills and valleys than does the present surface. The highest hills are in the southwestern part of the district and are of preglacial origin. Sheridan hill in Sec. 20, T. 42 N., R. 35 W. has an altitude of 1,840 feet and rises 460 feet above the lowest point in the district, the valley of the Paint river where it leaves the area in Sec. 36, T. 44 N., R. 34 W. The elevation of the rock surface near the center of Sec. 29, T. 43 N., R. 34 W. is 1,280 feet. Thus the maximum difference in elevation was in preglacial times at least 100 feet greater than it is now.

GLACIAL DEPOSITS.

In order that the non technical reader may better understand the following description of the glacial geology of the district, the discussion is prefaced by a brief explanation of the meaning of

the terms most commonly used in the description of glacial deposits.

In a collective sense deposits which are made directly and indirectly by continental glaciers are all included in the term *drift.* On the basis of composition, mode of deposition, and resulting topographic forms of the deposited material numerous subdivisions are made. Deposits referable more directly to ice deposition are composed of *till.* Till is composed mainly of clay, which may be more or less sandy, with varying quantities of rock fragments or boulders of sizes sometimes ranging up to many tons in weight. *Boulder clay* is another term for this class of deposits. On basis of topographic form, which is dependent mainly on mode of origin, deposits of till are subdivided into *drumlins, moraines,* and *till sheets,* the latter forming largely the *ground moraine.*

Drumlins are "smooth surfaced oval hills and ridges composed of till, the larger axes of which are parallel to the direction of the flow of the ice which shaped them." The ratio of short to long axes may vary from 1 : 1½ or 2 up to 1 : 20. Intermediate values are commonest. A *drumlinoid* is a hill composed of till and resembling in form a drumlin but being less symmetrically shaped although referable to the same mode of origin.

Moraines are formed at the margins of glaciers by the accumulation of till commonly in irregular ridges of hummocky or irregular character and usually accompanied by undrained basins or hollows which, when small and relatively deep, are termed *kettles.* A retreating glacier recedes haltingly, depositing at each stage of its recession a moraine. Sometimes during general recession an advance of the ice occurs and existing moraines are obliterated in the newly ice-covered area to be reformed during the succeeding halting stages of recession. Both the advance and retreat of a continental glacier is measured by the algebraic sum of numerous backward and forward movements. The records of recessions (moraines) are usually distinct, of advances, very much less distinct.

Till sheets are formed beneath the ice sheet and inside the moraines by ice deposition of till, i. e., mainly unstratified boulder clay. They form a blanket-like cover of greatly varying thickness above the rocks on which they are deposited. Till sheets are,

areally considered, the most important of the deposits formed by continental glaciers.

Deposits, more or less perfectly stratified, which are formed by the joint action of glacier ice and water, are described under the term *glacio-fluvial.*

Glacio-fluvial deposits are subdivided on basis of topographic form and mode of deposition into *valley trains, outwash aprons* (outwash plains), *eskers,* and *kames.*

Glacial streams escaping from beneath the ice are nearly always loaded with more sediment that they can carry, some of which is, therefore, deposited in the form of gravel, sand, and silt in the bed of the stream, forming a *valley train* beginning at the edge of the glacier and extending down the valley of the stream indefinitely. At the margin of a continental glacier *valley trains* may coalesce to form a broad marginal sheet of *debris* called an *outwash plain* or *outwash apron.* The valley train of continental glaciers is characteristic of the more rugged regions where the margin of the ice sheet may fringe out in narrow lobes extending down the valleys, being separated from one another by ridges of land forming the divides. "Where streams of considerable size form tunnels under or in the ice, these may become more or less filled with wash, and when the ice melts the aggraded channels appear as long ridges of gravel and sand known as *eskers.*"[1] Similar ridges may perhaps be formed in other ways as in valleys cut in the ice, bottomed by land but flanked by ice walls.

Kames are irregular hummocky hills of stratified sand and gravel heaped up at the edge of the ice in the mouths of ice tunnels and ice channels by escaping glacial streams. They are especially associated with marginal moraines.

Glacial deposits are often interbedded and intermingled with glacio-fluvial deposits, although the latter are especially characteristic of a zone extending to some distance inside the ice margin but having its greatest development in an outside marginal border.

In the Iron river district the glacial deposits are far more important than the glacio-fluvial deposits and, as will be explained below, antedate in age the formation of the latter, although in their present form the origin of both is a result of the action of the same ice sheet. (Wisconsin, or last continental glacier.)

[1]Chamberlin and Salisbury. Geology. Volume I, p. 306.

GLACIAL DEPOSITS IN THE IRON RIVER DISTRICT.

Till. By far the greater part of the surface of the Iron River district is covered with till. It seems originally to have formed beneath the ice a nearly complete cover above the underlying hard rocks. With the progressive exposure of the land as the ice retreated northward the present streams were formed. These became lines of glacial drainage down which glacial *debris* was carried and in part deposited on the valley bottoms as sand and gravel. Later, when the streams were no longer overloaded with glacial outwash they were able to erode channels in their aggraded beds, removing much of the sand and gravel with which their beds were clogged, and in case of the larger streams, frequently discovering the underlying hard rocks. The till areas of the present surface are found on the higher lands above the levels of glacial drainage.

The till is frequently composed almost entirely of firm boulder clay but more commonly the clay is somewhat sandy. The content of sand is usually sufficient to lighten the soil so that it maintains good tilth under cultivation but occasionally "sticky" or heavy clay soils occur. Stratified sand and gravel in the form of lenses are abundant in the till but are more common at buried horizons than on the surface. The most conspicuous character of the till is its unusually high content of boulders, a feature which may be observed in any section and is rendered prominent by the number of stone fences around cultivated fields and the large piles of boulders in the fields themselves, representing an expenditure of labor the magnitude of which can not be appreciated by one unfamiliar with agricultural conditions on the till soils.

Russell in 1905 made a study of the till areas of the southern part of the district,[2] which in all respects are similar to those in other parts of the area, and pointed out certain differences in character between the till of this region and that occurring west of Chicagon lake in the Crystal Falls district. The description of the gray till of the Iron River district is clear and accurate, but the author disagrees with Russell's ideas regarding the origin of the till and the direction of glacial movement. Russell says in part:[3] "In travelling west from Crystal Falls on the road leading to Iron River, one passes from a region where red till forms

[2]Russell, I. C. The Surface Geology of Portions of Menominee, Dickinson and Iron Counties, Michigan. Geological Survey of Michigan, Annual Report for 1906, pp. 7-91.
[3]Ibid. p. 50.

a veneer on the surface underlying rocks, to a region of massive moraines composed of gray till. The change occurs at the slough connecting Chicagon and Trout lakes, but whether these two lakes and the sluggish water channel connecting them are precisely on the boundary line or not remains to be determined.

The boundary referred to not only separates two regions in which the color of the soil is different, but several other contrasts in conditions accompanying this change, such, for example, as the thickness of the surface blanket of *debris,* prevalence of hard rock outcrops, character of the topography, abundance and nature of the boulders strewn over the surface, etc., as well as in variation in the aspect of the forests and conditions favoring agriculture. These contrasts are so definite and important that they demand a somewhat detailed consideration:

The red till on the uplands in the vicinity of Crystal Falls is on an average some ten feet thick, and forms merely a veneer on the glaciated rock surfaces. The gray till in the numerous bold hills to the west of Chicagon and Trout lakes is, in general, from one to two hundred feet thick, and in at least one locality, as shown by a well at Bates, is in excess of 212 feet deep."[4]

"The topography in the region where the red till forms the surface, is controlled to a great extent by the relief of the hard rock on which the till rests, and the hills are characterized by their comparatively small size and irregular outlines; while the topography of the gray till, as for example between Chicagon and Stanley lakes, has for its dominant features, bold, steep-sided, convex hills, with symmetrically curved bases, which efficiently conceal the relief of the rocks on which they rest. Accompanying this change in topography is an increase in the relief of the land above sea level. As one travels westward from Green Bay, the land rises gradually and * * * in the region to the west of Chicagoan and Trout lakes the broad uplands attain an elevation of 1,700 feet, and, in some instances approach 1,800 feet. The marked increase in elevation that occurs where one passes westward from the red to the gray till, coincides with the increase in thickness of the glacial *debris,* and seems to be due principally to this cause.

The heavy moraines of gray till to the west of Chicagon and

[4]For thicknesses of drift, see map. Plate I.

Trout lakes has a breadth of at least ten miles[5] and trends approximately northeast and southwest."

"The gray till is less sandy than the red till adjacent to it on the east, and as is judged, contains a larger percentage of clay-like material."

"Certain suggestive facts in reference to the relation of the red to the gray till may be mentioned, although they require supplementary evidence before their full significance can be satisfactorily determined. At the excavation made in connection with iron mining near Iron River and Stambaugh, gray till rests on reddish stratified sand and gravel, and along the road between Iron River and Atkinson to the northwest of a belt of bold moraines composed of gray till, the surface deposits consist of red till of the same general character as the main body of the red till which extends eastward from Crystal Falls, etc. These occurrences, and others of a similar nature, seem to show that the gray till was deposited at a later time than the red till and overlaps its westward extension. That such is in reality their true relation is little more than a suggestion * * *."

"No striæ have been observed which might serve to demonstrate the direction of glacial flow, but judging from the topography and the presence of sand and gravel deposits in the valley of the Iron and Brule rivers, etc., the ice lobe which formed the moraine lay to the northwest, and, on melting, its margin withdrew in that direction. Although only a beginning has been made in the study of the gray till, the conclusion is ventured that in the region examined, it pertains to the Chippewa lobe of the Wisconsin ice sheet."

Russell's rather tentative conclusions may be stated in brief as, (1) the so-called gray till of the Iron River district is younger and overlies the westward extension of the red till of the Crystal Falls district to the east of the Chicagon-Trout lake depression; (2) the topography of the till west of Chicagon and Trout lakes is morainal; (3) the gray till of the Iron River district is referred to the terminal moraines of the Chippewa lobe of the Wisconsin ice sheet which in this region retreated toward the northwest and presumably advanced from the northwest toward the southeast.

While there is some basis for distinction on the basis of *color*

[5]The gray till here extends from the east to the west side of the district and beyond—a width of at least upwards of twelve miles.—Author.

and general character of the boulder content between till of the Iron River district and that of the Crystal Falls district to the east of Chicagon and Trout lakes, this distinction is not a sharp one, and is certainly less conspicuous than might be inferred from the stress which Russell has laid upon it. There is little room for distinction even in color between the so-called *gray* till of the Iron River district and the *thicker* deposits of *red* till of the Crystal Falls district. It is suggested that the red color of the thinner parts of the till sheet of the Crystal Falls district is due in great measure to the fact that it *is* thin. The redness of the till is due to its content of red iron oxide which existed in the mantle of weathered rock from which the ice largely obtained the clay and boulders which form the till. It is usually true that local material is dominant in any till area and where the till is thin it is to be expected that local material would lend character to the deposit. It is equally true that in a thick till sheet such as occurs in the Iron River district local material is apt to be generally more abundant near the bottom than at higher horizons. Ferruginous rocks are abundant in both districts and their weathered mantle probably furnished an unusually large supply of red clay to the moving ice which deposited the till. The redness of certain basal portions of the Iron River drift, as noted by Russell, is not in itself a basis for correlation with the Crystal Falls drift on the one hand or for separation from the lighter colored deposits above it on the other.

That Russell should have considered the topography of the southern half of the Iron River district as morainal is somewhat surprising and it is believed that had his observation been more widely distributed his view would have been altered. The first impression that one gains from an inspection of the topographic map is that the N. E.-S. W. trend of the hills, valleys, and lakes, and the beautifully elongated and smoothly rounded forms of many of the hills were the result of *moving* ice and not of chaotic marginal deposition at successive fixed stages of ice retreat. The correctness of the impression is verified on examination of abraded rock exposures. There are few localities where satisfactory observations can be made, but a sufficient number were taken in the western half of the area to determine beyond doubt the direction of the ice movement, which is indicated on the map (Plate 1) by

arrows at the points where the observations were made. The data is tabulated below:

(1). N. E. ¼ of S. E. ¼ of Sec. 21, T. 42 N., R. 35 W.
S. 10° W.
S. 5° W.
S. 6° W.

(2). S. W. ¼ of S. W. ¼ of Sect. 6, T. 43 N., R 35 W.
S. 35° W.
S. 33° W.

(3). N. E. ¼ of N. E. ¼ of Sec. 1, T. 44 N., R. 36 W.
S. 20° W.

(4). N. W. ¼ of N. E. ¼ of Sec. 3, T. 44 N., R. 35 W.
S. 14° W.

At all of these localities glacial grooving is distinct especially in (1) and (4) where the grooves are inches in depth and occur on beautifully smoothed rock surfaces. In none of these localities are there more than one set of striæ or grooves and these are in each case almost exactly parallel.

Further evidence of the southwestward movement of the ice in this district is afforded by the relation between the direction of glacial grooving here and the orientation of the drumlinoid hills with the trend of morainal tracts to the north and south. Leverett has traced a morainic area from the vicinity of Hackley, Wisconsin, westward missing by only a few miles the southwest corner of the quadrangle. Northeastward another morainic tract extends northwestward through Amasa, touching the northeast corner of the Iron River quadrangle, and thence swinging a little more westerly across the country north of the district.[6] The trend of these two moraines is essentially parallel and nearly at right angles to the direction of glacial grooving and topographic orientation in the Iron River district lying between them.

Origin of the Drumloid Topography.—It is suggested that the drumloid character and "graining" of the topography of the quadrangle was produced by ice erosion of a till sheet. Glaciers, like rivers, under a certain class of conditions erode their beds, and under another deposit material upon them. If these are balanced

[6]Unpublished work of Frank Leverett. Field season of 1909.

equilibrium results, and neither appreciable erosion nor deposition occurs. Thus in the end, glacial erosion and deposition are exactly balanced. However, this equilibrium is rarely maintained at any given locality, the net result being in favor of one or the other of the opposing forces. In general, glacial erosion predominates near the center of ice dispersion, deposition in a zone sharply limited in one direction by a morainic margin marking the limits of ice advance, usually fringed by glacial outwash, and in the opposite direction, grading into an intermediate zone in which erosion and deposition are more nearly balanced. In a particular locality a glacier may erode at one time and deposit at another and there may be, in fact, several oscillations from the one condition to the other.

The erosive effects of moving ice on *hard rocks* are plainly recorded in polished, grooved, and striated rock surfaces and other markings on the rocks such as *chatter marks*[7] (crescentic cracks, usually convex toward direction of ice movement). Projecting rock masses are often smoothed and rounded forming *roche moutonné* and frequently glaciated rock knobs or hills exhibit *lee* and *stoss* effects due to greater abrasion on the side of the hill (*lee* side) opposed to the moving ice. On the other hand the erosive effects of moving ice on unconsolidated material such as a till sheet are not so easily discernible. If a glacier has eroded a till sheet earlier deposited by it or an older ice sheet, providing the deposit is not swept entirely away, the record of such erosion is preserved in the truncation of the interleaved, stratified sand and gravel beds which may terminate abruptly at the eroded surface or against the base of later drift deposited upon it. Hills and valleys are more or less perfectly oriented with their longer dimensions parallel to the direction of ice movement. The symmetrical, oval, till hills called drumlins are believed to have been formed in this way although such origin can rarely be proven and there are some geologists who believe that drumlins are more often formed by depositional rather than by erosive action. Russell[8] has shown that drumlins in the Menominee region, particularly in the vicinity of Hermansville, were almost certainly formed by ice erosion of a till sheet and it is probable that the same explanation applies to many other drumlin areas.

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[7]For discussion of manner of formation of chatter marks see Russell, I. C. Annual Report Michigan Geological Survey, 1906, pp. 31-33.
[8]Russell, I. C., Michigan Geological Survey, Annual Report, 1906, pp. 42-45.

In the Iron River district we have seen that the ice advanced from the northwest toward the southeast. By studies in comparison with other districts to the south, particularly in Wisconsin, it has been shown by the work of several geologists that the till sheet which covers this area was deposited by the Wisconsin or last continental glacier. If an earlier till sheet existed here it was swept southward by the Wisconsin glacier which left the record of its strongly abrasive action on the hard rocks, producing rounded, polished, and grooved rock surfaces. Later, a thick deposit of till was formed, filling the valleys and covering the tops of the hills, almost completely obscuring the topography of the rock surface beneath it. It is not inferred that abrasion preceeded deposition in all parts of the district, nor that the two processes did not occur simultaneously in different localities but the *end* result was deposition of a thick till sheet on an ice eroded rock surface. During the deposition of the till, water, formed largely by the melting of the ice, was active in building stratified lenses of sand and gravel which became interleaved with the unstratified deposits of boulder clay. Thus far in our analysis we are treading on safe ground but the question now arises, whether the *last* action of the ice sheet was erosional or depositional, whether the topography of the till sheet, which is *about* the same today as it was when uncovered by the ice, was *sculptured* out of a till sheet by ice erosion or was formed mainly by till deposition. Whatever may be the true explanation it is reasonably certain that *moving ice* was the agent which "grained" the topography, and in view of Russell's important determination of drumlin origin in the Menominee country it is thought probable that the action of the ice was erosional rather than depositional. A study of many of the drumloid hills for lee and stoss effects reveals the fact that the steeper slopes are often opposed to direction of ice movement. However, since it is known that glacial movement is often deflected mainly *around* an obstruction, however small it may be, with the result that steeper faces are often formed on the side of the obstruction presented to the moving ice (*stoss* side) rather than on the opposite side (*lee* side) this observation has no important bearing in this connection.

The topography of the Iron River district is drumloid, i. e., the elongated oval hills and chains of hills *approach* the drumlin in

[*] Ibid. pp. 44-45.

form but are less symmetrically shaped. A few of the hills in the central part of the district approach the symmetry of drumlins. They occur in a belt beginning near the center of Section 22, T. 43 N., R. 35 W., extending southeast to the oval hill crossed by the west line of Section 32, T. 43 N., R. 34 W. (See map, Plate I.) The rounded outlines of the drumlinoid hill just north of Iron River are shown in Plate 2.

THE TILL SOILS.

The character of virgin soils in forested areas is reflected to large extent in the forest growth upon them. In the Iron River district, and also in the Northern Peninsula of Michigan in general, the till soils support heavy stands of hardwood. Much of the primeval hardwood forest is still preserved on the till uplands of the Iron River district. Maple is the most abundant tree; birch, elm and basswood are plentiful; while hemlock, spruce, and pine occur to some extent in clumps and colonies usually on the more sandy till. It would be more accurate to say that the pine trees *did* occur for practically all that is now left of them are the stumps on which they grew. Even the occasional "lone pine" has fallen prey to the lumberman. Mining companies are persuing a far sighted policy in buying extensive hardwood tracts in order to insure themselves a supply of mine timber for the future. A considerable part of the forested till areas is held by companies and individuals for speculative purposes. The value of the hardwood and also the land on which it grows is steadily appreciating.

Sooner or later, with increase in population, and the consequent greater demand for land the till areas will be cleared of their forests and in their place will be cultivated fields. Experience has already proven that the till areas respond bountifully to cultivation. Good drainage is assured by the high and rolling character of the till and, as already stated, the till soils maintain as a rule excellent tilth under cultivation. Sticky clay or gumbo soils are exceptional owing to the sandy character of the till and the natural humus content of the soil layer. The summer season is short, but hay, small grains, and vegetables adapted to the climate yield excellent crops. The chief draw back to agriculture here is not the climate or poor soil but the extreme bouldery character of much of the till. This, however, is an obstacle which can be overcome here as it has been in other areas. The writer has been strongly impressed with

A DRUMLIN NORTH OF IRON RIVER. LOOKING NORTHWEST.

the agricultural possibilities of this area and believes, with Russell, that in time the main industry here will be based on agriculture. In agricultural possibilities the Iron River district is undoubtedly one of the most favored areas of the Northern Peninsula.

GLACIO-FLUVIAL DEPOSITS IN THE IRON RIVER DISTRICT.

The glacio-fluvial deposits of stratified sand and gravel are confined to the stream valleys and the depressions between the more elevated till areas. They were formed by running water derived from the melting glacier and in smaller part from the rains. During the time when these deposits were forming the streams were much larger and flowed more swiftly than at present. They were able to transport rock fragments several inches in diameter, large enough to be called boulders. That this is true is shown by the manner in which these fragments occur with the stratified finer materials making up the main body of the deposits. If we assume that precipitation was not greater than now, much the larger volume of water was contributed from the melting glacier. The volume of water and hence its speed of flow and carrying power were subject to great variations. This is indicated by the interstratification of coarse gravel and fine sand. A stream deposits on its bed only such material as it is unable to carry and the character and quantity of the deposits vary with the material contributed and the power of the stream to transport it. During the deposition of the glacio-fluvial deposits the streams were overloaded with sand and gravel and consequently were forced to deposit material in their beds. As the ice retreated northward beyond the headwaters of the streams in this area the glacial drainage was directed into other channels. When this occurred the streams which had been overloaded with sand and gravel were relieved. They shrank in volume to perhaps about their present size, but the shrinkage in volume was not relatively so great as shrinkage in material contributed at or near their sources. Consequently the action of the streams was reversed. Having less material than they were able to carry they began to acquire load from their beds by picking up material which had been previously deposited with the result that the present streams, i. e., the Paint, Iron, and Brule rivers have sunk their channels many feet below the old levels of glacial outwash. These levels which represent the former elevations of the

beds of streams are preserved in sand and gravel plains and *terraces* which occur along the valleys of the Paint, Net, Iron and Brule rivers.

Extensive sand and gravel plains occur at the junction of the North and South branches of the Paint river, at the mouth of the Net, and at the junction of the Iron and Brule. It is interesting to note that both the Paint and the Brule rivers have been deflected southward at their respective junctions with the Net and the Iron. The sand and gravel plains developed at these junctions seem to have been formed most largely by the tributary streams (Net and Iron) heading northward more directly toward the margin of the retreating ice sheet. The Iron seems to have continued to receive large amounts of glacial outwash after the ice had receded north of the valley of the Brule, and still later the Net was a carrier of outwash material after the ice had receded north of the valley of the Paint river.

The level of the glacial drainage on the Paint river near Atkinson is about 40 feet above the river, at the mouth of the Net about 50 feet, and in Sec. 36, T. 44 N., R. 34 W. about 65 feet. The fall of the present stream between Atkinson and Sec. 36, T. 44 N., R. 36 W. is, roughly, a little less than 5 feet per mile, while the level of the glacial drainage has a fall in the same distance of, roughly, 3½ feet per mile. The Iron river in its course across the district falls about 120 feet, or roughly a little less than 8 feet per mile, but the fall in the level of the glacial drainage is but slightly if any less.

THE GLACIO-FLUVIAL SOILS.

The sandy and gravelly outwash was formerly heavily timbered with pine. In every instance one can follow with the eye the line marking the level of glacial drainage on the sides of the hills by the change in forest growth. The change from soft wood to hard wood is abrupt and is brought out in very striking manner on the valley sides since the pine lands have usually been cut and burned over up to the hardwood line. These lands now support a second growth of jack pine and popple in contrast to the maple, birch, etc., of the forested till soils.

The sand and gravelly soils are little utilized for agricultural purposes. The till soils on the whole are much more desirable from the standpoint of fertility and durability. However, there

are soils on the outwash areas which should yield abundantly under proper cultivation. These contain considerable clay or silt content. The prospective settler or purchaser of these lands for agricultural purposes should investigate carefully before buying. Some areas have been repeatedly burned over to the final destruction of all or part of the natural humus content of the soil. These lands have received an injury which, under the conditions obtaining here, time alone can repair. If fires are prevented vegetation will slowly gain headway and finally in the course of years restore the humus to the soil.

ORIGIN OF THE LAKES AND DRAINAGE COURSES.

Character of the pre-glacial surface.—The lakes and drainage courses are of glacial origin, i. e., they were super-imposed on the drift covered surface exposed on the melting of the Wisconsin ice sheet. Just what relation, if any, exists between the present drainage lines and those which existed prior to glaciation can not be ascertained with certainty except in areas where rock exposures and drilling operations have furnished data for the reconstruction of the pre-glacial surface, as in the vicinity of Iron River and Stambaugh. Here, by assembling this data, we have been able to reconstruct in a general way the pre-glacial rock surface which is shown in green contours on the general map of the district. (Plate I). By reference to this map it will be seen that there are two well marked pre-glacial valleys extending in a general northeast direction. The southernmost heads southwestward into Section 10, T. 42 N., R. 35 W. and extends thence northeastward into the S. W. ¼ of Section 21, T. 43 N., R. 34 W. Probably it has a considerably greater northeastward extent but mapping must await further drilling in this direction. The drainage in the valley was certainly northeastward as far as the northern part of Section 32 T. 43 N., R. 34 W., where possibly it may have turned southeastward across the northeastern quarter of the section, tributary lines coming in here from the northwest and northeast.

A second pre-glacial valley seems to head eastward across Section 27, T. 43 N., R. 35 W. Eastward through Section 26 it coincides with the valley of Iron River which here turns south through a depression in the pre-glacial rock divide trending northeast through Stambaugh Hill while the older drift-filled valley continues a little northeasterly under Ice Lake. East of Ice Lake

the depression seems to divide into two, one swinging northeast and another southeast, probably connecting with the valley first described in the S. W. ¼ of Section 29, T. 43 N., R. 34 W.

It appears then that the Iron River cuts indifferently across valleys and divides in the old pre-glacial rock surface. The Brule river, on the other hand, seems to follow in a general way a pre-glacial valley, although its former bed does not closely coincide with the present one. The same is probably true of the Paint river from the vicinity of Atkinson eastward. With the probable exception of the Brule and Paint the changes in drainage lines produced by glaciation in the vicinity of Iron River and Stambaugh may be taken as an indication of what has happened elsewhere in the district.

The physical history of the district will be developed in a later chapter and it will therefore suffice here to look backward just far enough to construct a mental picture of its surface aspect just prior to glaciation. Just before the advent of the ice age the surface of the Iron River district presented a somewhat rugged aspect. The total relief was some hundred or more feet greater than the present. The hills did not present the smooth and rounded outlines of the present ones, but on the other hand were bolder and rougher and frequently presented very steep slopes. Sheridan hill was then, as now, the highest point in the district. This hill and the ridge south of the Brule river at Saunders dam have about the same appearance now as they possessed in pre-glacial time and they may be taken as examples of many others, which in the area to the north have been buried or partially buried in glacial drift. Yet it must be remembered in this connection that Sheridan Hill and the Saunders ridge, being made of hard siliceous rocks, stand higher above the surrounding rock surface than did other hills composed of softer rocks of the slate series lying north of the Saunders formation.

In pre-glacial time there were probably no lakes or swamps. The land was dissected by stream channels and was completely drained. The area had been subjected to stream erosion for long ages and considerable thicknesses of strata had been worn away. This is shown by the occurrence of flat lying remnants of Ordovician limestone and sandstone which formerly may have covered the entire district and above these it is possible that still younger

strata existed. These rocks were all but entirely removed before glacial time and the old erosional surface of the Algonkian rocks on which the Palaeozoic members rested and which now forms the rock surface beneath the glacial drift was again exposed. To accomplish this required a long period of erosion. Pre-glacial drainage was probably southeastward, as now, since the rock surface seems to slope in that direction.

Having before us a general idea of the preglacial surface we are better able to understand the changes in topography and drainage produced by glaciation. The preglacial topography of the Iron River district was such as to have presented little opposition to the southwestward movement of the continental ice sheet. The parallelism, in a single general direction, of glacial striation on rock surfaces and trend of glacially formed ridges and depressions show that the ice rode indifferently over hills and valleys alike, depositing here and eroding there, filling valleys, cutting down hills and generally obliterating drainage courses. Consequently, when the ice withdrew on its final northward retreat a new surface was uncovered. On this new surface the present drainage system developed. Water gathered in basin-like depressions forming lakes and ponds, low areas became swamps, and the newly formed major streams found their way southeastward in the direction of land slope by following the breaks in the southeastward trending ridges as in the case of the Iron River and in other cases perhaps by utilizing in part preglacial valleys not completely obliterated by glacial filling such as the valleys of the Brule and Paint. The minor streams naturally followed the depressions between the ridges, consequently the major streams receive their tributaries from the northeast and southwest.

CHAPTER III.

GENERAL GEOLOGY.

KEEWATIN AND LOWER HURONIAN.

It will be convenient in discussing the general geology of the district to consider each separate formation as a unit, beginning with the Archean or oldest rocks and taking each formation separately in the order in which it appears in the geologic column. Without knowledge of the geology of the other iron ranges of the Lake Superior region, especially those adjoining on the north and west, the task of deciphering the structure and age relations of the various formations would have been a more difficult undertaking. Where correlations with formations in adjoining districts to the west are uncertain local names have been introduced, i. e., Saunders formation, and Sheridan formation, to designate respectively the cherty dolomite and quartzite formation of Lower Huronian age typically developed near Saunders village, and the Palaeozoic member occurring in the vicinity of Sheridan Hill. In all other cases, i. e., where equivalency with formations heretofore described is more certain, the names in use in adjoining districts by the U. S. Geological Survey are extended to cover the equivalent formations in the Iron River district.

Owing to absence of rock exposures and other data there are meagre grounds for drawing formational boundaries on the Iron River map. Such has been attempted only where facts seem to warrant. Except in the case of the Vulcan formation colors have been omitted on account of the indefiniteness of formational boundaries. The map embodies known geologic information in so far as it can be shown on a map. The scale of the map, 2 inches to the mile, is large enough so that rock outcrops, drill holes, pits, shafts, etc., i. e., the data on which the geologist relies for drawing formational boundaries, can be shown. When such is done colors are largely unnecessary.

GENERAL STATEMENT.

The age relations of the various formations which have been discriminated appear in the table below:

Pleistocene deposits. Boulder till, sand and gravel.

Unconformity.

Paleozoic	Ordovician.	Sheridan Formation. Limestone, sandstone and conglomerate.	
	(Unconformity)		
Algonkian	Middle-Upper Huronian Group.	Michigamme (Hanbury) Slate	Hanbury Slate containing Vulcan iron formation. Basic volcanics associated with Hanbury Slate.
	(Unconformity?)		
	Lower Huronian Group.	Saunders Formation	Cherty dolomite and quartzite and slates.
	(Unconformity)		
Archean	Keewatin	Brule volcanics,—ellipsoidal greenstone and green schists equivalent to Quinnesec schists.	

Not considering the Pleistocene or glacial deposits, and with the further exception of a few remnants of Paleozoic rocks, the entire area is underlain by rocks of Algonkian and Archean (?) age, and these span the entire gap from the youngest Huronian, the Michigamme (Hanbury) slate, to the oldest Archean, the Keewatin (?) greenstones of the Brule formation. The Michigamme slates of the Marquette district have been traced by the U. S. Geological Survey southward into the Crystal Falls district where they seem to connect stratigraphically with the undivided Upper Huronian slate series of Clements, and westward with the same slate series in the Iron River district. The Brule volcanics in the southern part of the quadrangle are correlated with the Quinnesec schists of the Menominee district, but this correlation is more or less arbitrary since the relations between the Brule volcanics and the adjacent Saunders formation north of it and the Archean (?) granite a short distance south in Wisconsin are not known. Presumably unconformably above the Brule volcanics and Archean granites, the Saunders formation is correlated with the Lower Huronian Randville and Sturgeon formations of the Crystal Falls and Menominee

districts, and more provisionally with certain quartzites and conglomerates in seemingly like stratigraphic position with reference to the Basement complex and overlying slates in the southern Florence district.

From the base of the Saunders formation to the top of the Michigamme there is no evidence of an important unconformity in the Iron River district, but lack of evidence should not be taken as proof that unconformities do not exist. In fact the existence of great unconformities in the Huronian of the Marquette, Menominee and Penokee districts would lead one to believe, in the absence of conclusive proof to the contrary, that unconformities exist in the Huronian of the Iron River and Crystal Falls districts where, from the nature of the geological conditions, they are less easily found.

Since there are no known unconformities it is not apparent just where the dividing line between the Lower Huronian and the Middle-Upper Huronian should be placed. Some suggestion is afforded in the similarity of successions here and in other parts of the Menominee region. The Saunders formation is satisfactorily correlated with the Sturgeon and Randville formations of the Crystal Falls and Menominee districts. The Randville in the Crystal Falls district is overlain by the Hemlock volcanics at the top of which Clements places the separation between Lower and Upper Huronian. Likewise, in the Iron River district the Saunders formation seems to be overlain by a considerable thickness of volcanic greenstone with interbedded slate layers. Volcanic activity was recurrent at various intervals from this time on through the Michigamme. The geologic conditions during Saunders time were markedly different than those which characterized Michigamme time and it seems that the natural dividing line between the Upper-Middle and Lower Huronian is at the top of the Saunders formation, although it is recognized that in the interests of uniformity little objection can be offered to the correlation of the greenstones overlying the Saunders with the Hemlock of the Crystal Falls district, thus placing the division between Upper-Middle and Lower Huronian above rather than below the volcanics.

Within the Michigamme series there is no evidence of important unconformity. Finely conglomeratic layers associated with the

iron formation are frequently encountered in drilling, but since the entire series gives evidence of shallow water deposition little significance can be attached to these occurrences. Therefore, we are not able to discriminate between a Middle and an Upper Huronian series. Both series, if present, are included in the Michi-

		Series.	Marquette district.	Penokee—Gogebic district.
Algonkian.		Keweenawan series (copper bearing).		Gabbros, diabases, etc.
Algonkian.	Huronian Series.	Upper Huronian (iron bearing).	Michigamme slate (locally replaced by Clarksburg formation). Bijiki schist (iron bearing). Goodrich quartzite, containing productive detrital ores at its base.	Tyler slate. Ironwood formation (iron bearing and productive). Palms formation (quartz slate).
Algonkian.	Huronian Series.	Middle Huronian (iron bearing).	Negaunee formation (iron bearing and productive). Siamo slate. Ajibik quartzite.	
Algonkian.	Huronian Series.	Lower Huronian.	Wewe slate. Kona dolomite. Mesnard quartzite.	Limestone of Bad River. Quartzite.
Archean or Basement Complex.		Laurentian series (intrusive into Keewatin).	Granite, syenite, peridotite. Palmer gneiss,	Granite and granitoid gneiss.
Archean or Basement Complex.		Keewatin series (iron bearing).	Kitchi schist and Mona schist, the latter banded, and in a few places containing narrow bands of non-productive iron bearing formation.	Greenstones, green schists, and fine grained gneiss.

gamme of this report which is the equivalent of the Middle and Upper Huronian series of the Marquette and Menominee ranges.[1]

The correlation of the Pre-Cambrian series with that of the other Michigan ranges is shown in the following table. The correlations for the Marquette, Penokee-Gogebic, Menominee and Crystal Falls districts are those of the United States Geological Survey.

Menominee district.	Crystal Falls district.	Iron River district.
Hanbury slate, being in lower portions calcareous slates, etc., containing siderite and iron oxide. Vulcan formation, consisting of three members; Curry iron bearing member, Brier slate member, Traders iron bearing member.	Michigamme slate, containing a productive iron bearing horizon not separated in mapping for much of the district. With basic volcanics.	Michigamme slate containing iron formation lenses in at least four horizons. Productive in central part of district (vicinity of Iron River and Stambaugh). Associated with basic igneous rocks—mainly extrusive.
———(Unconformity?)———	———(Unconformity?)———	———(Unconformity?)———
Randville dolomite. Sturgeon quartzite.	Hemlock formation (basic volcanic). Randville dolomite. Sturgeon quartzite.	Saunders formation. Cherty dolomite, quartzite, and slate.
Granites and gneisses.	Granite.	Granite (in Wisconsin). (The age of these granites is doubtful. May be Huronian.)
Quinnesec schists. (Doubtfully referred to Keewatin. May be Upper Huronian).		Brule schists. Mainly ellipsoidal basalt. Exposures rare. (Keewatin are very doubtful. May be Huronian.)

[1] A Middle Huronian has recently been discriminated in the Menominee district by the U. S. Geological Survey.

KEEWATIN (?). THE BRULE VOLCANICS.

Basaltic extrusives with surface textures similar to those of the Quinnesec schists of the Menominee district and the Hemlock formation of the Crystal Falls district are exposed in isolated outcrops north and south of the Brule river in an east-west belt across the southern part of the district. These rocks possess no lithological or structural peculiarities which may safely be used as a basis for their correlation. Most of the outcrops are north of the adjacent Saunders formation, while a few are south of it, but since detailed mapping has not been done south of the Brule river the extent of the volcanics in this direction is not known. The volcanics are nowhere exposed in contact with the Saunders formation, hence their stratigraphic position can be determined only by their areal relation to the Saunders formation in reference to the structural attitude of the latter. The available data, while not conclusive for all parts of the Saunders formation, indicate a general northward dip. Applying this criterion, the volcanics north of the Saunders are probably stratigraphically above it and those south of it are stratigraphically below it.

Exposures of the Brule schists occur in the northern part of Sections 19, 20, 21 and 22, T. 42 N., R. 35 W. south of the Saunders formation. These are the only rocks in the area which are regarded as possibly Keewatin in age. The Keewatin age of these rocks is doubtful. There is evidence that they may be interbedded with the Saunders formation or they may be of even later age.

Interesting exposures occur in the S. E. ¼ of Section 21, T. 42 N., R. 35 W., beginning with a few low outcrops in the N. W. ¼ of the S. W. ¼ and extending with interruption for about a half mile in a direction slightly northeast, across the east line of the section just south of the east quarter post into Section 22, and at the dam on Brule river in the N. E. ¼ of the S. E. ¼ of Section 19 of the same township. In the first locality there are two main groups of exposures, the easternmost, crossed by the section line, shows beautifully developed ellipsoidal structure which is very obscure or absent in the westernmost outcrops.[2] The ellipsoids are of varying size up to above two feet in greatest dimension, being elongated in about E-W. direction, i. e., parallel to the trend of

[2]For description of the ellipsoidal structure see J. M. Clements, Mon. 36, U. S. G. S., pp. 112-126.

the folds and the schistosity in the rocks in this part of the district. There can be little doubt that the ellipsoids have been brought into this position by distortion accomplished by the forces which produced the general east-west folding and parallel secondary structures in the rocks of this part of the district. When there is considered the metamorphism and deformation to which these rocks have been subjected one wonders at the remarkably distinct outlines of the ellipsoids. That the ellipsoidal structure has not been obliterated or obscured is proof that whatever the agents and forces concerned in the anamorphism of the rock the end result as shown in the outlines of the ellipsoids was in the nature of a homogeneous strain. The ellipsoidal structure may be observed to best advantage on the polished surface of the exposure at the dam in Section 19, T. 42 N., R. 35 W. Here the flattening of the ellipsoids is most noticeable; the various individuals are fitted closely together, as though they had been molded and pressed together while in plastic condition, but the flattened ellipsoidal outlines are perfectly distinct.

Between the ellipsoids, mainly in the triangular spaces, occurs a matrix of chloritic and epidotic schistose material very frequently carrying considerable calcite or dolomite and some quartz. The quantity of matrix is small compared with the ellipsoids.

A structural characteristic of the Brule schists is the occurrence of torsion cracks. These are best shown on the non-ellipsoidal basalt exposed in the N. W. ¼ of the S. E. ¼ of Sec. 21, T. 42 N., R. 35 W. These cracks are usually open and from an inch up to three or four inches in length and may be arranged in sets forming a miniature *stockwerk*.

On fresh fracture these rocks are dense, fine grained, and grayish-green in color. Pyrite is irregularly disseminated through the rock in small grains, weathering out to form a pitted surface, calcite is abundantly present in fracture planes and chlorite is visible. A couple of slides from the last named locality were examined. Under the microscope chlorite is seen to make up the body of the rock, next in point of abundance is calcite, widely disseminated in clusters of crystals and ramifying in small veinlets, highly decomposed plagioclase is present and also pyrite, biotite, and epidote. The biotite in many specimens is porphyritic in appearance.

THE LOWER HURONIAN.

SAUNDERS FORMATION.

DISTRIBUTION.

The Saunders formation occurs in a belt of varying width extending in a general direction a little north of west across the southern part of the district and westward an unknown distance. Outcrops are infrequent on the whole and absent in large areas supposed to be underlain by this formation. It is well developed in Sheridan hill in Section 20, T. 42 N., R. 35 W. and vicinity. This hill owes its altitude, 1,840 feet, to the resistant character of the Saunders formation. Westward in Section 22, T. 42 N., R. 35 W., another hill rises to a height of about 1,800 feet and is presumably underlain by the Saunders formation. East of Saunders village and south of Brule river in Wisconsin this formation again assumes topographic prominence in an east-west ridge about two miles long. In the N. E. ¼ of the S. W. ¼ of Section 23, T. 42 N., R. 35 W., cherty phases are exposed in outcrops, slaty and dolomitic phases occur in a number of pits in Sections 26 and 35 and in outcrop on the west side of Brule river a short distance southwest of the north quarter post of Section 34.

LITHOLOGICAL CHARACTERS.

The Saunders formation embraces a wide variety of facies. Cherty dolomite is the most prominently developed. Associated with it is massive white and pink dolomite, quartzose dolomite, impure carbonate slates, quartzites, and talcose slates. The rocks of this formation are so rarely exposed that a general discription of the lithology and succession of the various facies of the formation as a whole should not be considered complete. A description of the rocks in known occurrences is given and such generalizations suggested as may be warranted by known facts.

PARTICULAR OCCURRENCES OF THE SAUNDERS' FORMATION.

Saunders Dam.—At the base of the ridge south of the Brule river at Saunders dam about a mile southeast of Saunders station is the best known single exposure of the Saunders formation. The rocks are exposed in a cliff some two or three hundred paces long from which massive blocks have been detached forming a talus

EXPOSURE OF BRECCIATED, SILICEOUS DOLOMITE OF THE SAUNDERS FORMATION AT SAUNDERS DAM.

which partly obscures the rock in place. Three distinct phases of the formation are exposed in the face of this cliff, viz., pure white, coarsely crystalline dolomite, banded cherty dolomite, and almost pure white and gray chert occurring in layers on the average about an inch thick. The rock in most places is brecciated and shattered to an extreme degree and the bedding is practically obliterated except in a few detached blocks of banded chert. The crushed and fractured cherty fragments are embedded in the greatest confusion in secondary infiltrated silica and carbonate, silica being dominant, forming a chert breccia. (See Plate 3.) In the cherty dolomite the more siliceous bands stand out prominently on weathered surfaces producing a ribbed appearance.

An analysis of the purer phase of dolomite by Prof. A. C. Clark of the Michigan Agricultural College gave:

ANALYSIS OF SAUNDERS DOLOMITE.

CO_2	43.90
SiO_2	6 10
$\left\{\frac{Al_2O_3}{Fe_2O_3}\right\}$	.49
CaO	29.33
MgO	19.98
H_2O at 105°	.07
H_2O at 115°	.05
	99.92%

Every gradation from the rock represented by this analysis into almost pure silica occurs in the exposure, but when the chert content becomes important it shows a tendency to segregate from the dolomite in bands.

Owing to the brecciated character of the rock satisfactory structural data is not afforded in this outcrop. At the north end the dip is apparently very steeply northward. The strike of the formation is undoubtedly that of the ridge which it forms, slightly west of north. Another similar exposure of the Saunders formation occurs in Wisconsin on this ridge about a mile west and one-fourth mile south of Pentoga station. From this point the dolomite ridge strikes northwestward to Saunders Dam then turns southwestward and dies out in about a mile and a half.

Railroad Cut South of Saunders.—On the strike of this dolomite

ridge in a cut on the Connorsville branch of the C. & N. W. Ry. at a point about 2,100 feet south of the railroad bridge across the Brule river the Saunders formation is again exposed. Here the rock is less siliceous than at Saunders dam and is intensely sheared with marked slaty structure of nearly vertical dip and almost east-west strike. In the south end of the cut where greatest shearing has taken place the rocks have weathered to a brick red. Toward the north end less weathered and more massive bluish phases occur. These rocks are seen under the microscope to consist chiefly of carbonate with coarse interlocking texture enclosing areas of finely granular silica. Sericite and ferric oxide are abundant and pyrite occurs in aggregates of small grains. The ferruginous appearance of weathered portions of these rocks is doubtless mainly due to the ferrous iron content of the bluish carbonate.

Sections 26 *and* 35, *T.* 42 *N., R.* 35 *W.*—Very similar phases of the Saunders formation are exposed in another locality about 3 miles west in Sections 35 and 26, T. 42 N., R. 35 W. In the bottom of a shallow well in the N. W. ¼ of the S. W. ¼ of Section 26, there is exposed an impure, bluish-gray, schistose, carbonate rock similar to those occurring in the C. & N. W. Ry. cut south of Saunders. The strike of the schistosity is N. 65° W., and the dip vertical. Similar rocks associated with well banded, varicolored, ferruginous and aluminous dolomitic slates occur on the dumps of pits dug by Mr. R. D. Williams in the S. W. ¼ of the S. W. ¼ of the section. Bedding in the slates is usually obscured by the schistosity but in a number of specimens bedding laminæ are well shown cutting the schistosity at a high angle. The ferruginous character of these slates is shown by the abundance of iron oxide developed in weathering which has here invited to exploration for iron ore. The following analysis of a typical specimen may be taken as characteristic:

ANALYSIS OF FERRUGINOUS DOLOMITIC SLATE.

CO_2	24.50
SiO_2	25.3
Al_2O_3	13.78
Fe_2O_3	3.25
FeO	2.93
MnO	Trace
CaO	17.28
MgO	7.86
Na_2O	.42
K_2O	2.68
Total H_2O	2.04
	100.04

More massive, quartzose and ferruginous dark colored dolomite occurs in a pit on the N. E. ¼ of the N. W. ¼ of Section 35, about 165 paces south and 30 paces west of the N. ¼ corner. The material from the bottom of the pit where weathering has been less effective is similar to that found in the well on the N. E. ¼ of the S. W. ¼ of Section 26.

A dark, bluish, schistose, slaty phase of the Saunders formation occurs in a fine exposure in the bank of the Brule river on the Wisconsin side, about 20 rods south of the section line between Sections 27 and 34, T. 42 N., R. 35 W. This rock shows no bedding but a perfect cleavage parallel to schistosity. The rock has parted into great plates striking N. 80° W. and dipping N. 57°. This exposure is locally known as the "Green Rock" or the "Green Stone." The latter name is inappropriate since the term "Green Stone" is used in geological nomenclature to designate an igneous rock of basaltic composition. There is no doubt that the rock in this exposure is a part of the aluminous and ferruginous slaty dolomite series uncovered in Sections 26 and 35, in railroad cut south of Saunders, and in Section 19, T. 24 W., R. 35 W.

A still more schistose phase of the Saunders formation occurs on the north side of the Brule river a short distance east of the west line of Section 19, T. 42 N., R. 35 W. The schistosity is about vertical and strikes N. 50° E. Although analysis was not made, the composition of the rock seems to be more nearly that of a true

mud slate than that of other described phases of the Saunders formation. In color it is dark bluish gray, on some cleavage planes a light silvery gray, doubtless due to development of sericite. Minute specks of pyrite are visible. plentifully disseminated through the rock. The pyrite content is largely responsible for the rusty weathering, but the appearance of some fresher surfaces suggests, also, the presence of ferruginous carbonate.

Sheridan Hill and Vicinity.—The Saunders formation is exposed in a number of places on the north side of Sheridan Hill, occurs on the dumps of many pits, mainly on the north and east sides, and outcrops eastward through the S. ½ of the S. W. ¼ of Section 18 adjoining. Here the formation shows a wide range of facies, but exposures are not frequent enough to disclose stratigraphic relations between them.

The dominant phase is a highly siliceous dolomite ranging in color from dark bluish gray through lighter shades of pink and yellow to almost white. The rock is everywhere crushed and shattered to an extreme degree. Original textures have been obliterated by recrystallization and rearrangement of the constituent minerals. The cherty siliceous material occurs in blebs, stringers, and confused masses of irregular fragments of various angular sizes and shapes, down to the smallest grains, forming breccias held together by siliceous dolomitic cement. Frequently the carbonates have been completely dissolved out leaving a mass of cherty quartz full of vugs and irregular cavities which are frequently lined with layers of minute crystals of secondary quartz, less often of dolomite. Iron oxide is widely disseminated through many of the specimens and frequently incrusts the walls of cavities.

Examined under the microscope these rocks without exception exhibit a closely fitting crystalline structure. The silica occurs in a fine mosaic which may surround areas of carbonate, sometimes as single crystals but more often in compound aggregates. Carbonate is sometimes included in a single quartz individual. Quartz is present in all specimens examined and in some exists to the exclusion of all other minerals. The carbonate, like quartz, varies in quantity but is always associated with more or less quartz. Iron oxide is usually present in greater or less amount, and in some slides is seen to have developed by oxidation of ferruginous carbonate. The iron now in the form of iron oxide, abundantly developed in

these rocks, was doubtless partly introduced by infiltrating solutions from sources outside the Saunders formation, but the greater part was originally present in the formation in the form of ferruginous carbonate. The bluish gray color of some of the dolomite is referred to its content of ferrous iron.

The siliceous dolomite grades into masses of almost pure quartz as at Saunders dam. Under the microscope these rocks appear as fine mosaics of completely interlocking grains of crystalline silica.

Another phase of the Saunders formation which is important, judging from the number of its drift boulders seen in this vicinity, has not been observed in natural outcrop. It is a massive, pinkish-red, fine grained quartzite. This rock is reported by Mr. O. W. Wheelwright to have been encountered at a depth of 244 to 254 feet by Mr. Oberg in a churn drill hole about 375 paces north and 300 paces west of the south quarter corner of Section 17, T. 42 N., R. 35 W. A sample of cuttings from this depth is identical with float boulders found on the surface. In the hole the quartzite is reported to be overlain by dolomite and soft slaty material, probably soapstone.

Soft, yellowish-white to red and ferruginous talcose slates occur in a couple of pits about 400 to 425 paces west and 75 to 100 paces south of the N. E. corner of Section 20, T. 42 N., R. 35 W. The strike of the bedding is N. 45° W. and dip 70° N. E. The bedding is cut by a well defined cleavage with strike parallel to the bedding and dip N. E. at an angle of 85°. There can be little doubt that these slates are a part of the Saunders formation, although they have been considered by some explorers to belong to the iron bearing series of the Upper Huronian. They are probably interbedded with the siliceous dolomite which outcrops both north and south of their line of strike within 350 paces of the pits and may be on the same horizon as similar slates reported to have been encountered in the drill hole described above.

Eastward, the Saunders formation assumes topographic prominence in a hill in the N. W. ¼ of Section 22, which rises to an elevation of 1,780 feet, outcrops in siliceous phase in the eastern part of the N. E. ¼ of the S. W. ¼ of Section 23, and is reported to have been encountered in the bottom of a well in the S. E. ¼ of the S. E. ¼ of the same section. A specimen of siliceous, pink

dolomite said to have been taken from the bottom of this well was shown the writer. There is little doubt that the Saunders formation underlies the prominent hill crossed by the south line of Section 24, beyond which, eastward, it probably crosses the Brule river into Wisconsin.

It should be noted here that the volcanic greenstones in the apex of the sharp northward bend in the Brule river in Sections 19 and 30 and in Section 29, T. 42 N., R. 34 W., are in the strike of the Saunders formation and may be interbedded with it.

RELATIONS TO ADJACENT FORMATIONS.

The few occurrences in the above widely separated localities form the only basis for present knowledge of the lithology and distribution of the Saunders formation. These occurrences are indicated on the map (Plate 1) and form as may be seen only meagre data for drawing formational boundaries. The boundaries indicated have been drawn by the writer to exclude the outcrops of the volcanic greenstones, overlying the Saunders on the north, and the Brule volcanics on the south. Not a single contact between the Saunders and adjacent formations has been found and the formational boundaries are but roughly approximate at the best. Doubtless the north boundary is more nearly correct in the vicinity of Sheridan Hill and Saunders dam than elsewhere, since in these localities the data is more nearly adequate, but between these two localities data is lacking for drawing an approximately correct boundary. With the exception of perhaps about three miles in the southwestern part of the quadrangle, the south boundary of the Saunders formation is in Wisconsin and was therefore not mapped.

Since the Saunders formation is stratigraphically the lowest known sedimentary rock in the district and is adjacent to the Archean on the south and, furthermore, is lithologically similar to the Lower Huronian of the Crystal Falls and Menominee districts on the east it is thought to be of Lower Huronian age. In as much as the Lower Huronian is elsewhere unconformably above the Archean, such relations are inferred to exist between the Saunders formation and the Archean south of it. Whether the Brule formation, here very doubtfully correlated with the Keewatin, is unconformably below or is interbedded with the Saunders formation is not here apparent.

The Saunders formation is overlain on the north by volcanic

greenstone interbedded with more or less slate. There is no evidence of any kind to indicate either the presence or absence of an erosion interval between them. Possibly the greenstones are to some extent interbedded with the Saunders. Both formations are, in general, steeply inclined northward, and have been affected by the same general folding, hence their approximate structural conformity is inferred.

STRUCTURE.

Satisfactory structural observations can not be made on known exposures. In the cherty and quartzitic phases bedding is destroyed by excessive brecciation, in the slaty phases it is obscured by schistosity and in the purer, massive, dolomitic phases bedding is not shown, being doubtless destroyed by recrystallization and rearrangement of the minerals in the rock. In the north face of the ridge at Saunders dam there are banded cherty phases showing steep northward dip but folding and brecciation are here of such character as to indicate that these dips may be local. Where developed the schistosity is usually steeply inclined northward and is about parallel to the trend of the formation. Distinct bedding is shown in slaty fragments on the dumps of pits in the S. W. ¼ of Section 26, T. 42 N., R. 35 W., but here the pits are filled with debris and the rock could not be observed in place. At this place the schistosity cuts the crumpled bedding laminæ of the slate nearly at right angles. As the schistosity is elsewhere steeply inclined northward it may be inferred that the dip of the bedding is here northward at a very low angle. A northeastward dip is shown in talcose slates near the base of the northeast side of Sheridan Hill. These observations are unsatisfactory but considered with the position of the Saunders formation between the older rocks south of it and rocks to the north which are certainly younger they indicate a general northward dip.

East of Section 21, T. 42 N., R. 35 W., the Saunders formation seems to widen and swing southeastward. This is probably due to flattening of dip on an anticlinal cross fold. If the axis of this fold be extended northward it coincides approximately with the direction of the axis of a broad anticline in the northern part of the district. As will be pointed out later, it is probable that the entire district has been folded on this axis thus extended.

Thickness.—A close estimate of the thickness of the Saunders

formation can not be made. If we take the width of the formation across Sheridan Hill at 4,000 feet and assume the dip to be 75° the thickness will be 3,750 feet. Doubtless the formation is very thick but the above figures may be a thousand or more feet too great. The average dip of the rocks in Sheridan hill may be less than 75° and the calculation is further weakened because the apparent increase in thickness due to minor folding cannot be approximated.

CHAPTER IV.

THE UPPER HURONIAN GROUP.

Michigamme (Hanbury) Slate Series.

DISTRIBUTION AND GENERAL CHARACTERS.

The Michigamme slate formation occupies much the larger part of the district. It is limited on the south by the Saunders formation and extends north, west, and east beyond the limits of the district, in the latter direction connecting with the Upper Huronian slates of the Menominee, Crystal Falls and Florence districts.

The rocks include a wide variety of facies. Graywackes, with textures varying from conglomeratic to fine grained, and their schistose equivalents are dominant in the northern part of the area where they are interbedded with lenses of black pyritiferous and carbonaceous slates, micaceous and chloritic slates, and narrow lenses of iron formation which occur in the vicinity of Atkinson, on Morrison creek, in Section 24, T. 44 N., R. 35 W., and doubtless in other areas which are drift covered. Southward the clastics become finer grained on the whole and less metamorphosed. Slates are dominant and iron formation is more extensively developed. However, graywackes and fine conglomerates are not wanting and are often found associated with rocks of the Vulcan iron formation. Black, pyritiferous and carbonaceous slates are common associates of the iron formation.

The relations between the various facies of the Michigamme formation are those of gradation and interbedding. Any single type of the rock may grade by mineralogical and textural variations into any other type. The variations take place in the direction of bedding and across it with the result that, in general, the entire formation is made up of dovetailed lenses of various dimensions and compositions with indefinite gradational borders between them. While gradation is the rule, abrupt transitions from one type to another frequently occur, especially between black slates and iron formation.

Ellipsoidal, agglomeratic, and tuffaceous, extrusive, greenstones

are interbedded at various horizons with the Michigamme formation. They seem to be especially abundant at the base of the series just north of the Saunders formation and at higher horizons, particularly in the central and in the northern parts of the district. Of less common occurrence, there are igneous rocks of similar composition but with well developed interlocking crystalline texture. These are probably intrusive.

STRUCTURE.

In attempting to work out the structure in detail of the group one is met with the insupperable difficulty of identifying horizons in the slates. Rocks of identical character are repeated at different stratigraphic horizons and the same stratigraphic horizon may exhibit, even in a small area, facies which are of very different composition and texture. Inasmuch as this fact is not appreciated by many who explore for iron ore in this district it should be emphasized here.

(1) *Any given horizon of the Michigamme series cannot be depended on to maintain the same character over any considerable area. It follows that* (2) *cross sections through the same stratigraphic horizons may differ widely in a given small area and consequently* (3) *similar sequence of formations in adjacent areas does not necessarily imply stratigraphic equivalence unless the various similar beds are known to be continuous from the one area into the other.* Especially is this true if the two areas compared are widely separated. Observations in the field and in mine workings and microscopic study of the rocks establish beyond doubt the truth of the above statement as will appear on later pages.

The iron formation layers locally serve as guides to the structure in the southern part of the district, and in the northern part, where graywacke phases are especially abundant and exposures are more numerous, general lines of structure are well brought out. Beginning on the east side of T. 44 N., R. 34 W., along the Paint river, the rocks are observed to strike slightly west of north and to dip vertically or steeply to the northeast. Following up the Paint river to its junction with the Net and thence westward toward Atkinson, the strike swings sharply westward, and then south of west, the dip varying from north to northwest. Southwest of Atkinson to the limits of the district and at least several miles

beyond, the southwesterly trend continues and the dips are to the northwest. Brittle layers have been gashed by tension cracks, in general, normal to the strike. Cleavage is subordinate to bedding in the northeastern part of the district, but westward the rocks become more and more schistose until the bedding is mainly obliterated. This is perhaps due chiefly to change in character of the sediments. The rocks in the northeastern part of the area are commonly coarse grained to finely conglomeratic, becoming finer grained toward the west. In this direction the dip of schistosity becomes on the average flatter and where compared with the bedding the two structures generally dip northward, the schistosity being the more steeply inclined.

The general structure of the northern part of the district is that of a truncated, broad, northward pitching, assymmetrical anticline, with steeper limb on the east and axis trending 15° or 20° east of north. If this axis is projected southwestward across the center of the district it will coincide, with slight allowance for change in direction, with the axis of the anticlinal cross fold affecting the Saunders formation indicated in the widening and the southeastward swing of the formation in the big bend of the Brule river. That the entire district has been folded on this axis is borne out by surface and underground observations in the vicinity of Iron River and Stambaugh and southeastward and northward. North of Iron River the strikes are approximately east and west, so far as known, corresponding to their position on the axis of the anticline. From Iron River southeastward the general trend of the Michigamme formation is undoubtedly southeastward, although it is affected by an intricate and complex system of cross folds. South of the Baltic and Zimmerman mines there are no exposures but the formation of necessity swings more to the eastward in line with the Saunders formation below it. The general strike at the Chicagon mine, six miles east of Iron River, seems to be northeast thus being in line with the strike of the rocks on Paint river to the north. A northeast trend is also indicated in the N. W.-S. E. elongation of the magnetic field in Section 33, T. 43 N., R. 34 W. In general, then, it seems that the Michigamme formation enters the district from the east with northwest trend, swings westward in the entral part of the district, and then southwestward.

While the folding on the slightly northeast-southwest axis de-

scribed is a major feature of the structure it is believed to be subordinate to folding in the opposite direction especially in the southern part of the district. Here the dips in the Michigamme formation are, on the whole, steeper than in the northern part of the district although locally they vary from nothing to 90° due to complex minor folding. The general east-west trend of the steeply inclined Saunders formation and the east-west strike of the secondary structures in it and the adjacent greenstones indicate the main structural line for this part of the district. Since the Upper and Lower Huronian are in structural conformity here as well as eastward in the Crystal Falls, Menominee, and Florence districts, the Michigamme formation with its interbedded lenses of Vulcan iron formation which are best developed in the southern part of the area may be expected to extend beneath the drift west of Iron River beyond the limits of the district. The westernmost exposure of the Vulcan member is in the S. W. ¼ of the S. W. ¼ of Section 33, T. 43 N., R. 35 W.

It follows from the above that in passing from the southern to the northern part of the area successively younger strata are encountered although doubtless there is considerable, though not determinable, repetition of horizons due to folding.

The truth of this may not be apparent from a study of the map (Plate I) except to those closely familiar with the geology of the district, therefore, the argument in support of the hypothesis is outlined in the following paragraphs.

Broadly considered, the rocks north of the Saunders formation may be divided into three belts, each having broad, distinctive, lithologic characteristics. The southernmost of these belts (1) lies between the Saunders formation on the south and a belt composed dominantly of greenstone on the north. This belt carries the iron ore producing area and is composed chiefly of slates carrying iron formation lenses. The second belt (2) is several miles in width but the boundaries are ill defined. It enters from the east and swings in a convex northward curving course across the district parallel to the trend of the Paint slates north of it. This belt carries greenstone outcrops in its eastern, western, and central parts; the presence of interbedded slates is inferred though not as yet proven. The northern belt (3) comprises slates and graywackes with their altered equivalents, interbedded volcanic greenstone and lenses of

iron formation. In discussion of general structure these three belts may be considered as units. The possibility of major faulting as a factor influencing field distribution is not considered since major faults are not now known to be present. The southernmost belt (1) is adjacent to the Saunders formation on the south except for the presence of a belt of greenstone of undeterminable but varying thickness between and is, therefore, younger than the Saunders. Now if the central belt of greenstone (2) is equivalent to that adjacent to the Saunders formation, the structure of belt (1) is necessarily *synclinal* since an anticlinal structure would throw it *beneath* the Saunders formation, where it obviously does not belong for reasons advanced in the discussion of the Saunders formation. If the structure of belt (1) is *synclinal* it follows that the structure of belt (2) is *anticlinal.* Now if belt (2) is anticlinal the rocks of belt (1) should occur adjacent to belt (2) on the north, but in place of them there occur a series of rocks of such decidedly different characteristics on the whole that they cannot be correlated with those of belt (1) except on the assumption that the conditions of original deposition were such as to account fully for the lithological dissimilarity of the two belts. Such an assumption is not violent but its verity is doubted notwithstanding that the writer is fully impressed with the belief that lithologic variations on a given horizon may be rapid and complete even in a small area.

The alternative hypothesis, which is the one here accepted, places the rocks of belt (3), the Paint slate series, stratigraphically *above* the volcanic greenstones of belt (2) and these in turn above the slate-iron formation rocks of belt (1). Within each belt there is probably considerable repetition by folding, since calculations of thickness based on observed dips would otherwise indicate thicknesses so great as to be far beyond the limits of reasonable probabilities. It should be recalled here that belt (2) is continuous with a greenstone area extending eastward to Crystal Falls, which Clements correlated with the Hemlock greenstone which overlies the Randville dolomite, and mapped with anticlinal structure[1] thus placing it below the Michigamme series (the "undivided Upper Huronian" of Monograph 36, U. S. Geological Survey) of the Crystal Falls district which is areally continuous with the Michi-

[1]Clements, J. Morgan. U. S. Geological Survey, Monograph 36, p. 74 and Plate IV.

gamme slate series of the Iron River district. The evidence deduced from studies in the Iron River district favors the view that these greenstones which are characterized by the textures of surface flows and volcanic ejectamenta are interbedded with the Michigamme slates and are well up in the series.

The foregoing account of the general structure is purely descriptive and offers no explanation of the direction of application, and the character of the forces which produced the folding. When it is said that the area has been folded in two general axial directions it is not implied that general folding in one direction preceded or followed general folding in the other direction. The probabilities are that forces tending to produce folding in both general axial directions were operative at the same time. The general structural elements are not complete but are segments of larger structural features affecting a much wider area, and should be recognized as such in any discussion which seeks to elucidate the manner in which deformation was effected. A broad discussion of this nature is beyond the scope of this report.

THE VULCAN FORMATION (IRON BEARING).

DISTRIBUTION AND EXPOSURES.

The term Vulcan has been applied to the iron bearing members of the Michigamme slate following the use of this name by the United States Geological Survey to designate equivalent formations in the Menominee and Crystal Falls districts. There are few exposures of the Vulcan formation. Our knowledge of the distribution is based mainly on occurrences in underground workings and in drill holes put down in search of iron ore and therefore is largely limited by the extent to which these operations have been conducted. There are indicated on the map those areas which are known to be underlain by this member and the position of the drill holes in which the formation has been penetrated. All of these areas include more or less slate, and interbedded slate is shown in many of the drill holes which are indicated as cutting the Vulcan member. Most of the drill cores were examined but some are unavailable; in the latter case we have had to rely on the superintendent's and drill runner's records. An attempt has been made to discriminate between the more unaltered iron formation rocks on the one hand and ferruginous cherts and slates and iron

ores on the other. There are all gradations between the various phases of the iron formation, but since the ores and highly oxidized phases are related to structural conditions which largely influence ore concentration it is thought that the discrimination attempted will have some practical usefulness in suggesting lines for further exploration.

A discrimination between ferruginous chert and the cherty carbonates and slates of the Vulcan formation is made by explorers in the field. Rocks here called ferruginous cherts and slates in local terminology are termed "ore formation" in recognition of the association of ferruginous cherts and slates with iron ore. The more or less unaltered rocks of the Vulcan formation are usually included by the drillmen in the term "slates," the different kinds of slate being discriminated mainly on the basis of color, as gray slate, black slate, etc. However, the terminology used by explorers is not uniform and for this reason where cores or cuttings are not preserved the drill records very often offer little information regarding the character of the rock penetrated. In a district like this, where almost the only working information available is that afforded by drilling and underground exploration, great care should be exercised in obtaining and preserving drill cuttings and cores. Most companies and explorers are now doing this, but records of many of the earlier explorations and some of the more recent ones were not preserved.

Referring to the central part of the district, it will be seen by a study of the data on the map that the relations between slate and iron formation are exceedingly complex and in most instances it is impossible to exclude the slates from any considerable area. The explanation lies in the interbedding of the slate and iron formation coupled with complicated folding.

The iron formation lenses are closely and intricately folded and interbedded with the associated slates and are usually steeply dipping. Erosion has cut deeply into the series doubtless removing the iron formation over considerable areas where it once existed. Where exposed the iron formation occurs at the surface mainly in narrow bands, frequently twisting and contorted, but in some cases retaining an approximately straight course for distances of several miles, as in the James belt. With this general idea in mind it will be readily understood that any attempt to

draw formational boundaries of the Vulcan member will be more misleading than helpful. The distribution and structure will be further discussed in connection with descriptions of particular areas.

LITHOLOGICAL CHARACTERS OF THE VULCAN FORMATION.

The Vulcan formation is made up of ferruginous cherts and slates, slaty and cherty iron carbonate rock, magnetitic, chloritic, sideritic slates, and iron ores. The various facies possess no characteristics which are peculiar to this district. These rocks have been repeatedly described in detail in the United States Geological Survey monographs on the Penokee-Gogebic, Marquette and Menominee districts and some of the descriptive paragraphs which follow are necessarily partly a repetition of matter found elsewhere in print. For the benefit of readers who may not have access to the above volumes and for the purpose of emphasizing the significant characteristics of the Vulcan formation, short descriptions of the main phases of the rocks are here given.

Slaty and Cherty Iron Carbonates.—The iron carbonate rocks may be recognized in the field by their finely laminated and platy structures, commonly gray color on fresh surfaces, dense, fine-grained texture, and rusty-brown, sugary weathering on exposed surfaces and in fracture planes. The color is subject to variation, frequently becoming dark with impurities such as carbonaceous matter, but the banding, texture, and weathering furnish criteria by which these rocks may be easily discriminated from others with which they are associated.

Siderite (iron carbonate) is the most important mineral. It occurs in rounded grains and in rhombs some of which in rare instances may be seen without the use of a lense. Siderite may make up almost the entire body of the rock, but in this district such occurrences are rare. Silica, mainly in finely crystalline form but in smaller part chalcedonic or semi-amorphous, and in many cases detrital, is an essential mineral. The proportional amounts of silica and siderite may vary widely, both minerals are practically always present but either one may be dominant. *Cherty siderite* or *sideritic chert* are terms which are used to express the dominance of one or the other of these minerals.

The character and composition of the cherty iron carbonate varies with the variety and relative abundance of the accessory minerals

of which a number are nearly always present. The most prominent of these are calcium and magnesium carbonates, pyrite, biotite, and sericite. Earthy and carbonaceous material is frequently abundant and hematite is often present as an oxidation product of the siderite. When the siderite becomes completely or nearly completely oxidized the rock becomes either *ferruginous chert* or *ferruginous slate.* The average mineral composition of the rocks which may be classed as cherty and slaty iron carbonate would be difficult to express. Some idea may be gained from the following tabulation of the minerals found in microscopic examination of 16 typical specimens nearly all taken from drill holes in the productive part of the district.

Minerals found in 16 typical cherty and slaty iron-carbonate rocks in the Iron River district:

Number of thin sections examined		16
" " " " containing	siderite (and other carbonates)	16
" " " " "	quartz	16
" " " " "	chlorite	10
" " " " "	carbonaceous and earthy material	8
" " " " "	hematite	7
" " " " "	iron pyrite	6
" " " " "	biotite	5
" " " " "	sericite	3
" " " " "	titanite (alteration product of biotite?)	1

A specimen of cherty iron carbonate taken from one of the pits of the Gleason Exploration in the N. E. ¼ of Section 33, T. 43 N., R. 34 W., was analyzed by Prof. A. J. Clark of the Michigan Agricultural College. For purposes of comparison this analysis is tabulated below with others representing typical cherty iron carbonate rocks from the Penokee-Gogebic and Vermilion districts and from Gunflint Lake in Minnesota.

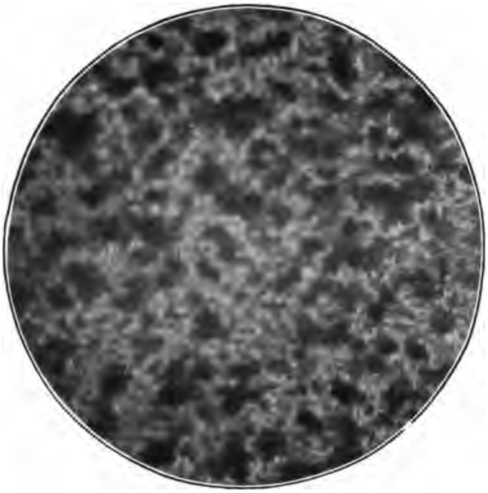
ANALYSES OF CHERTY IRON BEARING CARBONATES.*

	Penokee-Gogebic.				Gunflint Lake.		Iron River.
	1.	2.	3.	4.	5.	6.	7.
SiO_2	15.62	28.86	46.01	3.16	58.23	46.46	66.01
TiO_2	....	.20	0.12	....	trace	trace	....
Al_2O_3	4.27	1.29	0.83	.08	.06	0.24	3.50
Fe_2O_3	8.14	1.01	1.35	.93	5.01	0.64	8.32
FeO	32.85	37.37	26.00	15.18	18.41	26.28	9.90
MnO	5.06	0.97	2.09	1.15	0.25	0.21	0.60
CaO	0.81	0.74	0.63	26.65	0.38	1.87	0.52
MgO	2.66	3.64	2.86	11.01	9.59	3.10	0.50
CO_2	30.32	25.21	17.72	41.10	5.22	19.96	10.71
P_2O_5	....	trace	.07	.06	0.03	0.13	....
FeS_2	....	....	.11	.34	0.14	0.11	....
Na_2O	....	....	....	....	....	....	0.42
K_2O	....	....	....	....	....	....	0.13
Water at 105°	....	none	....	....	....	....	....
Water at 110°	....	....	....	....	0.07	0.07	....
Water at red heat	0.63	0.68	1.71	0.54	2.01	1.15	....
Total	100.41	99.97	99.50	100.20	99.40	100.22	100.61

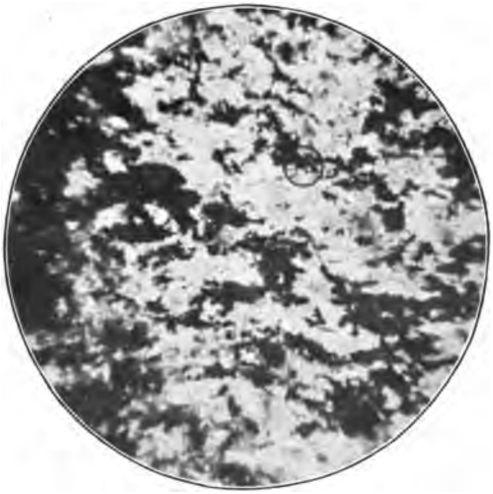
*Analysis Nos. 1, 2, 3, 4, 5, 6 are taken from the U. S. G. S., Monograph 19, p. 192.

While the analyses of these seven types of iron bearing carbonates vary considerably in proportions of the various constituents essential similarity in constitution is apparent. In the Iron River specimen the content of alumina and silica is conspicuously high and the predominance of ferric over ferrous iron is unusual. The specimen analyzed was examined microscopically for ferric iron as hematite or hydrous hematite, but none was found. It is possible that error was made in determination of ferric iron. (Plate 4A.)

Ferruginous cherts and slates.—Ferruginous slates and cherts are common associates of the ore bodies. They represent gradational phases between cherty iron carbonate on the one hand and iron ores on the other. In local terminology they are called "ore formation." *Ferruginous slate* is derived from cherty iron carbonate by complete or partial oxidation of the iron bearing carbonates *in place,* which means that oxidation is accomplished without extensive rearrangement of the materials in the rock. The



(A) CHERTY IRON CARBONATE FROM THE VULCAN FORMATION, NEAR CENTER OF THE N. E. ¼ OF SECTION 35, T. 43 N., R. 34 W. IN PARALLEL POLARIZED LIGHT WITHOUT ANALYZER, MAGNIFIED 80 DIAMETERS. THE DARK SPOTS ARE SIDERITE. THE WHITE MOTTLED AREAS ARE MAINLY FINELY CRYSTALLINE QUARTZ.



(B) FERRUGINOUS SLATE FROM THE VULCAN FORMATION, WILDCAT SHAFT. ABOUT 1,450 FEET SOUTH OF THE CENTER OF SECTION 18, T. 42 N., R. 34 W. PARALLEL POLARIZED LIGHT WITHOUT ANALYZER. THE DARK AREAS ARE HEMATITE, SECONDARY AFTER SIDERITE. THE LIGH AREAS ARE MAINLY QUARTZ.

banding or lamination shown by the cherty iron carbonate rocks is preserved in the ferruginous slates and emphasized by the conspicuous colors of the red and yellow oxides of iron. The "red slates" so frequently penetrated in drill holes are good examples of this type of rock.

As katamorphism progresses both the silica and iron contents of the rock become more extensively rearranged with tendency toward segregation. Frequently the silica and iron oxide occur in alternate bands or layers forming the "banded ore formation" of this district, which is equivalent to the "soft ore jasper" of the Marquette district. More often the ferruginous cherts are broken and crushed forming a breccia, in which the banding is partially or wholly obliterated. The breccia in extreme phases presents the appearance of jumbled masses of irregular cherty fragments, in color varying from pure white to red and yellow according to the amount of disseminated iron oxide in them, to dark colored if high in carbonaceous matter, irregularly mixed with stringers and pockets of iron oxide which form ore bodes when of sufficient size to be mined.

Stated briefly, the difference between *cherty iron carbonate* and *ferruginous slate* consists only in the substitution in the latter of iron oxide in the place of the iron bearing carbonates of the former. In the *ferruginous cherts* the silica and iron oxide have been extensively rearranged. The rearrangement is accomplished by recrystallization, which involves solution of the silica and iron, transportation to varying distances in the rock, and redeposition from solution.[1]

During the process of recrystallization there is a tendency toward segregation of the iron oxide in "bands and shots" of ore which, mixed with chert, forms the *"mixed rock and ore"* of the miner's phraseology. When the process of segregation becomes sufficiently well advanced ore bodies result. The genetic relations between ferruginous cherts, "mixed rock and ore," and iron ore are well understood by the miners as gradational phases are exhibited in every mine in the district. The only practical difference between ferruginous chert, "mixed rock and ore," and iron ore is in relative proportions of iron oxide and silica. When ferruginous chert

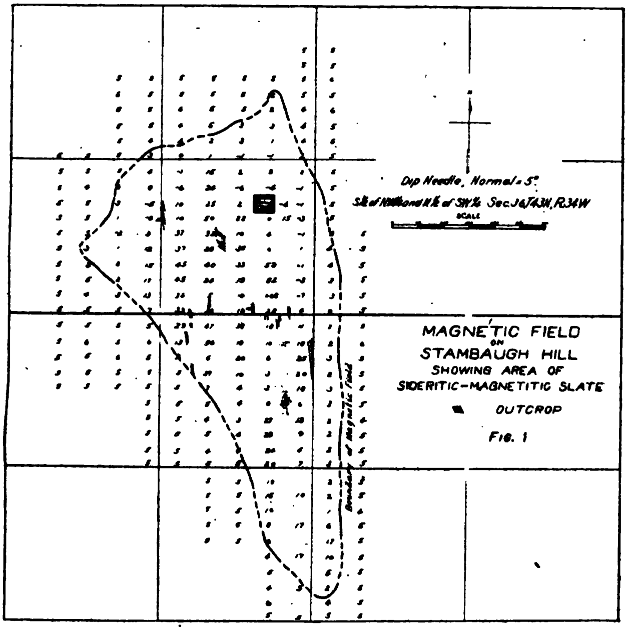
[1]The banding in ferruginous cherts is thought in many if not the majority of cases to be the result of original deposition rather than segregation during subsequent alteration although the *tendency* toward segregation cannot be denied and may in some cases emphasize and in other actually produce alternate bands of silica and iron oxide.

or "mixed rock and ore" grades into iron ore by decrease in silica or chert content and increase in iron content the "ore formation" is said by the miners to "clean up," an expression which exactly fits the case. (Plate 4B.)

Magnetitic-Chloritic-Sideritic Slates. — Magnetitic-chloritic-sideritic slates are *known* to occur in but one locality, viz., on Stambaugh Hill, Section 36, T. 43 N., R. 35 W., in an elongated area of about forty acres. The general structure is simple, the strike being N. 30°-35° W., and the dip vertical or highly inclined toward the southwest 75°-90°. Superimposed on this structure are minor folds producing a wavy and contorted appearance of the banding conspicuous on outcrops. The magnetic properties of these rocks furnish a means by which they may be easily mapped without the aid afforded by natural exposures. The magnetic field on Stambaugh Hill is shown in figure 1 in relation to outcrops. The elongation of the field is in the direction of strike of the rocks. A similar magnetic field, likewise elongated in a direction believed to be that of the strike of the rocks, N. W.-S. E., occurs in the S. W. ¼ of Section 33, T. 43 N., R. 34 W. This field (see fig. 2) is of about the same size and character as the one on Stambaugh Hill and probably outlines an area of magnetitic slates similar to those in the latter locality, although in the absence of exposures such cannot be certainly affirmed. Other magnetic fields would doubtless be found if the area were carefully magnetically surveyed. It is regretted that the means at the disposal of the writer did not permit of such survey being undertaken.

As shown in the exposure on Stambaugh Hill the magnetitic-chloritic-sideritic slates exhibit prominent banding, well marked on outcrops by alternating laminæ of lighter and darker shades. Weathered surfaces are yellowish to brown, fresh surfaces are gray to black, the shade of color depending mainly on the relative abundance of magnetite. Thin bands of chert and jasper are occasionally found but they are discontinuous and not characteristic of the rock as a whole. All of the minerals are microscopic in size giving the rock a dense aphanitic texture.

Under the microscope these rocks are seen to be made up of the following minerals: chlorite and magnetite are abundant and about equally developed; carbonate, probably mainly iron bearing, is somewhat less abundant although conspicuously present; sericite is present in small crystals oriented with long axes in plane of bed-



MAGNETIC FIELD ON STAMBAUGH HILL SHOWING AREA OF SIDERITIC-MAGNETITIC SLATE

FIG. 1

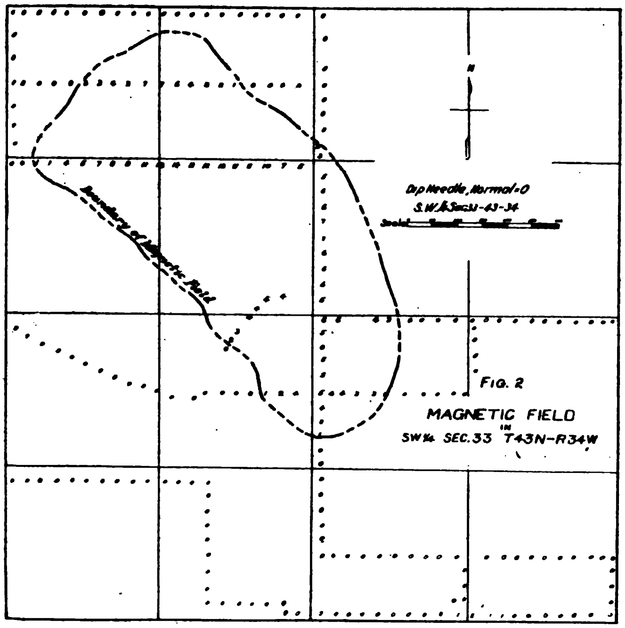


FIG. 2

MAGNETIC FIELD IN SW¼ SEC. 33 T43N-R34W

ding; hematite occurs in small flakes and grains and quartz is present in extremely minute particles disseminated throughout the rock. Associated with these minerals there is a dense felty viriditic matrix in which the individual particles cannot be differentiated with a magnification of 600 diameters.

The magnetitic-sideritic slates are probably the metamorphic equivalents of impure carbonate slates so abundantly developed in the Vulcan formation. The original minerals seem to have been carbonate, quartz and aluminous and feldspathic mud. From these have developed, by metamorphism, magnetite, chlorite, sericite and hematite.

In composition and origin these rocks present some analogy to the amphibole-magnetite rocks of the Penokee-Gogebic and Marquette districts which, as shown by VanHise, have developed through anamorphism of a cherty iron carbonate rock. That the analogy is incomplete seems to be due to differences in composition of the original rock and degree of metamorphism.

In the Penokee-Gogebic and Marquette districts a rock consisting almost entirely of carbonate and quartz was anamorphosed to a rock containing magnetite, amphibole, (actinolite or grünerite) and quartz with minor amounts of biotite and sericite. In the Iron River district a rock composed originally of carbonate and aluminous and feldspathic muds with some quartz was anamorphosed to a magnetitic-chloritic-sideritic-sericitic slate.

The Iron River rocks, compared with their type analogues of the Penokee-Gogebic and Marquette districts, are finer grained, contain much less quartz and magnetite, have abundant chlorite instead of amphibole and carry more residual carbonate. Their fineness of grain and the presence of more residual carbonate indicate a lower degree of anamorphism.

For the Penokee-Gogebic rocks VanHise has shown by microscopical study that magnetite is secondary after siderite and amphibole is formed by interaction between siderite and quartz. Type reactions are given below:[3]

$$(1)\quad \overset{\text{siderite}}{3FeCo_3} + O = \overset{\text{magnetite}}{Fe_3O_4} + 3CO_2$$

$$(2)\quad \overset{\text{siderite}}{2FeCO_3} + \overset{\text{pyrite}}{FeS_2} + 2H_2O = Fe_3O_4 + 2H_2S + 2CO_2$$

$$(3)\quad \overset{\text{siderite}}{FeCO_3} + \overset{\text{quartz}}{SiO_2} + 2H_2O = FeSiO_3 + CO_2 + 2H_2O$$

[3]United States Geological Survey Mon. 19, p. 392.

The genesis of the magnetite in the magnetitic-sideritic slates of the Iron River district is somewhat obscure. The magnetite is much more commonly associated with chlorite than with siderite. Perhaps 90% of the magnetite grains are actually embedded in chlorite while pseudomorphs of magnetite after siderite have not been observed. However, the material surrounding some of the magnetite grains resembles in part chlorite and in part carbonate to the extent that frequently the color and characteristic pleochroism of chlorite in parallel polarized light without the analyzer gives way to the double refraction and interference colors of carbonate under crossed nicols. Evidently this material is neither chlorite nor carbonate, but its occurrence in association with carbonate, magnetite, and chlorite suggests a dependent relation upon the formation of the two latter most abundant secondary minerals. It is possible to conceive that magnetite and chlorite are developed simultaneously by interaction between the carbonates and the aluminous constituents of the rock and the phenomena above described may be taken as evidence that such reaction has occurred. If we take the mineral mesitite to represent the composition of the carbonates and the mineral kaolin that of the associated aluminous muds, the character of the reaction may be represented by the following equation:

$$\overset{\text{Mesitite}}{4(MgFe)\ (CO_3)_2} + \overset{\text{Kaolin}}{Al_2O_3.2SiO_2.2H_2O} + 30 + SiO_2 =$$
$$\overset{\text{Chlorite}}{Hg(MgFe)_5Si_3O_{18}} + \overset{\text{Magnetite}}{Fe_3O_4} + 8CO_2$$

The other two important secondary minerals, biotite and sericite, are common constituents of metamorphosed aluminous and feldspathic mud slates.

The magnetitic-chloritic-sideritic slates are to be considered the metamorphic equivalents of an original carbonate slate in which the associated constituents were mainly of the nature of aluminous and feldspathic muds instead of quartz. (Plate 5A.)

SOME PARTICULAR CHARACTERISTICS OF THE VULCAN FORMATION.

The descriptions given in preceding paragraphs refer to *type phases* of the Vulcan formation and it must not be understood that *every* specimen that might be taken will fall readily within one of the three main classes of rocks described. The relations between the various types are those of gradation and any one of the three main types of the Vulcan formation may grade by relative increase

of clastic material into the slates and graywackes of the Michigamme formation.

Clastic material in the Vulcan formation.—The Vulcan formation is characterized by the presence of associated clastic material and resulting alteration products. Fragmental quartz grains are abundant in many specimens and are clearly distinguishable from the matrix of crystalline silica of fine interlocking texture in which they are often enclosed. Less commonly there are grains of feldspar. If the intermixed clastic material is of very fine grain impure sideritic slates or impure ferruginous slates result and these, by decrease in the carbonate and the cherty constituents, grade into ordinary aluminous and siliceous slate. Through metamorphism the impurities in the iron formation rocks give rise to secondary products, mainly chlorite which is nearly always associated with biotite and lesser amounts of sericite. Carbonaceous impurities are especially abundant and are responsible for the dark color of much of the cherts of the iron formation. Pyrite is a common associate of the carbonaceous impurities, but may occur in smaller amount in the purer phases of the rock. In the least altered rocks the iron is present mainly as carbonate, being changed to limonite and hematite as oxidation progresses, but by anamorphism occasionally giving rise to magnetitic-chloritic slates usually carrying more or less residual iron carbonate.

In short the typical iron bearing rock of the Vulcan formation—mainly a cherty iron carbonate—shows all possible gradational phases to slate on the one hand which is nearly always highly chloritic, usually biotitic and sericitic, and frequently more or less carbonaceous grading into highly graphitic varieties, to graywacke on the other, and, moreover, it is to be noted that, considering the formation as a whole, the purer forms of iron formation rocks are subordinate in amount. A laboratory study of these rocks discloses the characters that they may be inferred to possess from their intimate field relations to various types of interbedded slates and graywackes. Indeed, it is impossible to describe adequately the rocks of the Vulcan formation without reference to the clastic rocks with which they are so closely associated.

Occurrence of altered greenalite in the Vulcan formation.—As was to be expected, microscopic study has revealed the probable original presence of small quantities of greenalite in the Vulcan

formation. What are believed to be the altered forms of this mineral are present in some sections but generally they are absent or at least not recognizable.[4]

Spurr[5] found in 1894 that the least altered phase of the iron formation member (Biwabik formation) in the Mesabi district of Minnesota contains numerous small green granules of ellipsoidal and ovoidal form which, from their general habit and composition, he considered to be glauconite. Later study by C. K. Leith, while confirming in general the earlier work of Spurr, brought out the fact that the composition of the green granules is dissimilar in several essential respects to that of glauconite and does not conform to that of any other known mineral. Leith, therefore, concluded to call the green granules greenalite.

Greenalite is essentially a hydrous ferrous silicate of iron corresponding to the formula $FeSiO_3.nH_2O$. The ferrous iron may be replaced by variable small quantities of magnesia. In constitution greenalite is analogous to siderite ($FeCO_3$) the ratio between base and acid being the same 1:1.

The general association of greenalite and siderite in the iron formations of the Lake Superior region is an interesting fact established since the work of Leith on the Biwabik formation of the Mesabi district. In the latter district the ferrous silicate, greenalite, greatly predominates over the ferrous carbonate, siderite, as the original iron bearing mineral from which the ore bodies have been mainly derived by processes of oxidation and concentration. Northeastward, in the Animikee district iron formation equivalent to the Biwabik of the Mesabi district contains proportionately more carbonate, while in the iron ranges south of Lake Superior iron bearing carbonates are vastly more abundant than the ferrous silicate, greenalite.

In the Iron River district greenalite was probably present in greater abundance in the Vulcan formation than might be inferred from a microscopical examination of miscellaneous thin sections. In the more highly altered phases all traces of greenalite have been apparently obliterated by recrystallization and rearrangement in different new combinations of the elements forming the minerals

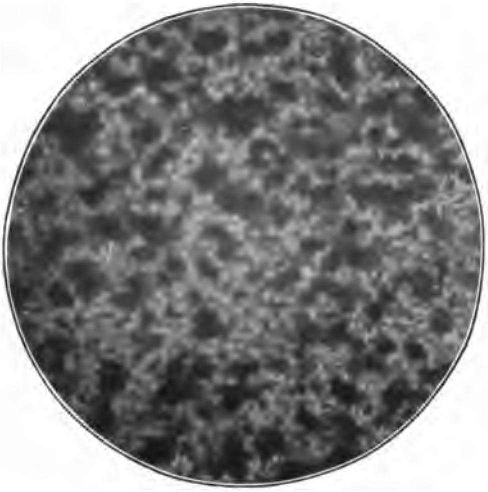
[4]For detailed description of greenalite, see C. K. Leith, United States Geological Survey, Mon. 43, pp. 101-115.
[5]Spurr, J. E. The iron bearing rocks of the Mesabi range in Minnesota. Geological and Natural History Survey of Minnesota, Bulletin 10, 1894, pp. 1-268.

in the rock. It was only after identification of better preserved forms in a few sections that its original presence in others was determined. Various late stages of the alteration of the greenalite granules are observable in thin sections, but nothing approaching unaltered greenalite has been found and it should be stated that the forms described in the following paragraphs as altered greenalite appear as such only to the observer who is familiar with the occurrence of the mineral in rocks where the fresh and all the various altered conditions have been fully studied as by Leith in the Mesabi district of Minnesota.

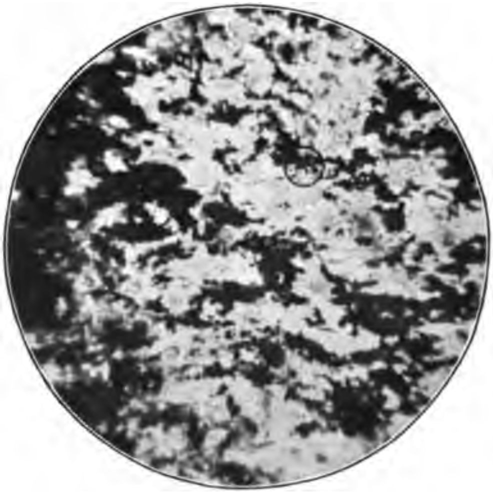
A particular occurrence of altered greenalite.—The occurrence of altered greenalite from a depth of 215-219 feet in a drill hole 200 feet north and 150 feet west of the center of Section 29, T. 43 N., R. 34 W., is characteristic for the entire formation so far as studied. Under the miscroscope the rock is seen to consist of varying proportions of quartz, carbonate, hematite, chlorite, sericite, amphibole, apatite, and confused masses of undifferentiated viriditic materials. The most conspicuous mineral in the thin section is quartz occurring in rounded to subangular grains, frequently as isolated individuals surrounded by other minerals, but also often clustered in colonies forming quartz mosaics. The quartz is free from strain shadows and in many cases carries inclusions of sericite in single crystals and in aggregates. Almost as common as sericite as an inclusion is a green amphibole. Its usual habit is an elongated fibrous shred or prism, rarely it is stumpy or tabular. In the fibrous habit the extinction is nearly parallel to the elongation, but the tabular crystals show angles of 26° to 30°. Some of the quartz is also penetrated by crystalline needles of hematite.

The notable feature in this rock is the occurrence of oblong areas consisting largely of semi-crystalline to finely crystalline silica. Associated with the silica in these areas are fine meshes composed of sericite, a little chlorite, and some of the green amphibole. Hematite is nearly always present and sometimes, but not often, carbonate, while grayish and greenish felty stringers and masses of unidentified alteration products may occur anywhere and occasionally are abundant. Some of these areas are identical in shape with greenalite granules described by Leith* and are plainly the survivors of an original mineral with rounded to ellipsoidal

*Ibid. pp. 101-102.



(A) CHERTY IRON CARBONATE FROM THE VULCAN FORMATION, NEAR CENTER OF THE N. E. ¼ OF SECTION 35, T. 43 N., R. 34 W. IN PARALLEL POLARIZED LIGHT WITHOUT ANALYZER, MAGNIFIED 80 DIAMETERS. THE DARK SPOTS ARE SIDERITE. THE WHITE MOTTLED AREAS ARE MAINLY FINELY CRYSTALLINE QUARTZ.



(B) FERRUGINOUS SLATE FROM THE VULCAN FORMATION, WILDCAT SHAFT. ABOUT 1,450 FEET SOUTH OF THE CENTER OF SECTION 18, T. 42 N., R. 34 W. PARALLEL POLARIZED LIGHT WITHOUT ANALYZER. THE DARK AREAS ARE HEMATITE, SECONDARY AFTER SIDERITE. THE LIGHT AREAS ARE MAINLY QUARTZ.

outline. Furthermore, in mineral composition they exhibit some analogy to altered greenalite granules in the Biwabik formation of the Mesabi district. The only marked difference consists in their content of sericite and chlorite which seems to take the place of the amphibole in similar forms in the Biwabik formation, although, as stated, amphibole is present in small amount in some of them. The outlines of the oval areas are more distinct when looked at in light transmitted through the polarizer only, in fact with crossed nicols the outlines are usually not discernible, being obscured by the double refraction of the chert. (Plate 5B.)

With the forms described in the preceding paragraph there occur others which are similar in outline but show a zonal arrangement of the constituent minerals.

(1) A clear, colorless quartz individual is surrounded by a border of carbonate and hematite about equally abundant. A second border, usually not complete, is composed of finely crystalline silica.

(2) The core is composed of finely crystalline silica which is surrounded by a border of hematite which, in turn, is enclosed in a second border of carbonate and the latter is encircled by a broken rim of hematite.

(3) Anyone of the minerals, hematite, carbonate, or quartz may form the core.

(4) The zonal structure may be absent, the minerals occurring in a confused aggregate retaining the oblong or rounded form.

The forms described in (1), (2), and (3), *may* be of concretionary origin, yet the zonal or concentric structure rarely approaches perfection and in the majority of forms is merely *suggested.* I cannot escape the conclusion that forms (1), (2), and (3) are merely modifications of the commoner form (4) in which concentric arrangement is not shown. It should be stated in conclusion that the identification of these oval and rounded mineral aggregates as derivatives of greenalite granules rests solely upon their similarity in shape and composition to analogous forms *which are known to have had such derivation.*

LOCAL MAGNETISM IN THE VULCAN FORMATION.

While in general the Vulcan formation is not magnetic, there are a few local areas in which magnetism is well developed. Other magnetic areas would probably be discovered were the district care-

fully magnetically surveyed. We have already referred to the magnetic line apparently following the northern edge of the greenstone in Sections 21, 22, and 23, T. 42 N., R. 34 W. Whether this line is caused by magnetism in the greenstone or in one of the lower members of the Michigamme formation is not known. The latter is considered the more probable.

A magnetic field of irregular and widely varying strength covers about 40 acres occupying the crest of Stambaugh Hill in the W. ½ of Section 36, T. 43 N., R. 34 W. (See fig. 1.) Here the rocks are well exposed in numerous outcrops on the top of the hill. The dip is about vertical and strike slightly west of north, which is the direction of elongation of the field. Under the microscope these rocks are seen to contain innumerable small grains of magnetite. Descriptions of these rocks have already been given, pp. 56-59.

A magnetic field of about the same size and shape occurs in the S. W. ¼ of Section 33, T. 43 N., R. 34 W., (see fig. 2), but here the field is elongated in a northwest-southeast direction which is likewise believed to indicate the strike of the rocks at this locality, although no exposures occur.

Local magnetism occurs in isolated patches in Sections 35 and 36, T. 43 N., R. 34 W. Here the magnetic rock is mainly a graywacke carrying abundant magnetite.

HORIZONS AT WHICH THE VULCAN FORMATION OCCURS.

From the foregoing it will have been anticipated that the Vulcan formation is not confined to a single horizon in the Michigamme slates. From analogy with Vulcan beds of the Menominee and Crystal Falls districts it might be inferred that they form at least two horizons near the base of the Michigamme slate series but it is reasonably certain that there are at least four iron bearing horizons in the Iron River district without making allowances for the possible occurrence of two or more horizons in the producing part of the area in the vicinity of Iron River and Stambaugh. In fact slate and iron formation are interbedded in such a way that any horizon of the Michigamme slate may somewhere become iron bearing. There are areas where the facts are more nearly expressed by the phrase, "Vulcan formation containing lenses of Michigamme slate" than "Michigamme slate containing Vulcan iron formation," and this is especially true of the central and southern parts of the

district. Any attempt to unravel the structure of the Michigamme series which does not take into account these relations will certainly lead to erroneous results.

The known main occurrences of the Vulcan formation may be referred to three different areas, viz., (1) the Jumbo belt, just south of the Brule river in Florence county, Wisconsin, about 1½ miles east of Saunders, (2) the central area of unestablished boundaries extending north, east, south, and west of Iron River, and (3) the northern area including the Morrison creek belt in Section 24, T. 44 N., R. 35 W., and the Atkinson belt southwest of Atkinson. From the general structure of the district it is apparent that these different areas occupy as many different general horizons of the Michigamme formation, the southernmost belt being at the lowest horizon, the central area being somewhat higher, and the northern area being still higher than the central area.

DISTRIBUTION AND STRUCTURE OF THE VULCAN FORMATION IN PARTICULAR AREAS.

THE JUMBO BELT.

The only natural exposure on this belt occurs on the east side of Brule river about 200 paces east of the S. E. corner of the N. E. ¼ of the S. E. ¼ of Section 22, T. 42, N., R. 34 W. The rock is mainly a finely banded cherty iron carbonate locally altered to ferruginous chert and interbedded with carbonaceous any pyritic black slate. The strike is east and west and the dip is about vertical on the average although it varies widely on the limbs of the minor folds. From this exposure the formation is traced eastward for three quarters of a mile by numerous test pits of the old Jumbo exploration. The pits are now filled with debris but the dumps disclose slate and iron formation of the characters shown in the outcrop on the river. In the dump of the old Jumbo shaft at the east end of the belt are found an abundance of much altered greenstone, black carbonaceous and pyritic slate, roughly banded iron formation carrying much pyrite and secondary quartz and a small quantity of lean iron ore. The relations between Vulcan formation and greenstone are not shown but the two formations are probably interbedded. Interbedded siliceous, pyritiferous slate and highly altered greenstone are well exposed in an outcrop on

the south bank of the Brule river just north of the Vulcan formation and seem to lie conformably above it.

The Jumbo iron formation-slate belt is overlain on the north, in probable conformity, by extrusive ellipsoidal greenstone which is well exposed in numerous outcrops north and south of the C. & N W. R. It is underlain by the Saunders formation which occurs about one quarter of a mile south. The Jumbo belt extends east and west beyond known limits. (See fig. 3).

THE CENTRAL AREA.

General Distribution.—This is the iron ore producing area of the Iron River district. The boundaries are not yet definitely known and are being rapidly widened by exploration. Taking Iron River and Stambaugh as a center, iron formation is known to occur northward to the southern part of Section 11, T. 43 N., R. 35 W., eastward to the Chicagon mine in the N. E. ¼ of Section 26, T. 43 N., R. 34 W., southeastward to the N. W. ¼ of the N. W. ¼ of Section 16, T. 42 N., R. 34 W., and westward to the S. W. ¼ of the S. W. ¼ of Section 33, T. 43 N., R. 35 W.

The area seems to be limited on the south by greenstone probably interbedded with slate. Connecting the scattered outcrops of greenstone occurring just north of the Saunders formation, a belt of varying width is formed extending across the entire district. While it is certain that this belt as shown on the map contains considerable interbedded slate and possibly iron formation, it seems to mark in a general way the south limit of the main slate-iron formation series. Beginning at the outcrops in Section 23, T. 42 N., R. 34 W., a magnetic line, probably marking the north edge of the greenstone, extends slightly north of west for about two miles where it dies out. If extended, this line would pass just north of the greenstone exposure in the N. W. ¼ of the N. W. ¼ of Section 21. Thence the boundary swings more to the north and passes through the Wildcat shaft near the center of the south half of Section 18, and thence just north of the outcrops of greenstone in the N. ½ of the N. ½ of Section 13, T. 42 N., R. 35 W. Farther westward the boundary cannot be followed from lack of exposures and exploration.

Data for drawing a north boundary of this area are entirely inadequate. Probably it has no well defined north limit. A few

greenstone outcrops occur in a broad belt of country several miles wide beginning about the middle of the east side of the district, where they connect with the greenstone area extending eastward almost to Crystal Falls, extending thence northwestward to the middle of the district, and thence southwestward. In this belt there are a greater number of square miles of territory than outcrops, and those that occur are confined to the eastern, central, and western parts. However, the wide distribution of the few outcrops that are known indicate a belt composed dominantly of greenstone extending across the district in a curving course in line with the structure of the graywacke and slate area north of it.

Of the structure and distribution of the Vulcan formation within this area we are by no means fully informed. Exploration has been actively prosecuted for the past four years but is still far from adequate. Locally, in the mine workings, the structure is well known but it is sometimes very difficult to connect the structure and stratigraphy shown in workings on a single 40 acres with those of an adjacent 40 acres. The explanation for this complexity has already been discussed.

Beginning in the southeastern part of the district, iron formation occurrs in drill holes in the N. W. ¼ of the N. W. ¼ of Section 16, T. 42 N., R. 34 W., and thence, in a curving line parallel to the supposed north boundary of the greenstone belt on the south, northwestward to the Zimmerman mine. Eastward from Section 16 the iron formation extends in all probability through Sections 15 and 14 and perhaps still further to the east but in this direction exploration has not yet been carried. It is a favorable line for exploration. North and east of this belt borings have generally penetrated black slate.

From the Zimmerman and Baltic mines the general course of the formation is northwestward up the valley of the Iron river. In detail the structure is exceedingly complex and thorough understanding will involve a description of the structure and succession in every mine on the belt. The Vulcan formation is here very generally underlain and interbedded with black slate and is usually in highly inclined position. The formation attains its greatest known width on the Caspian mine location where, with allowances for repetition by cross folding, it is probably above 300 feet thick.

At the Hiawatha mine and thence westward for about a mile, the

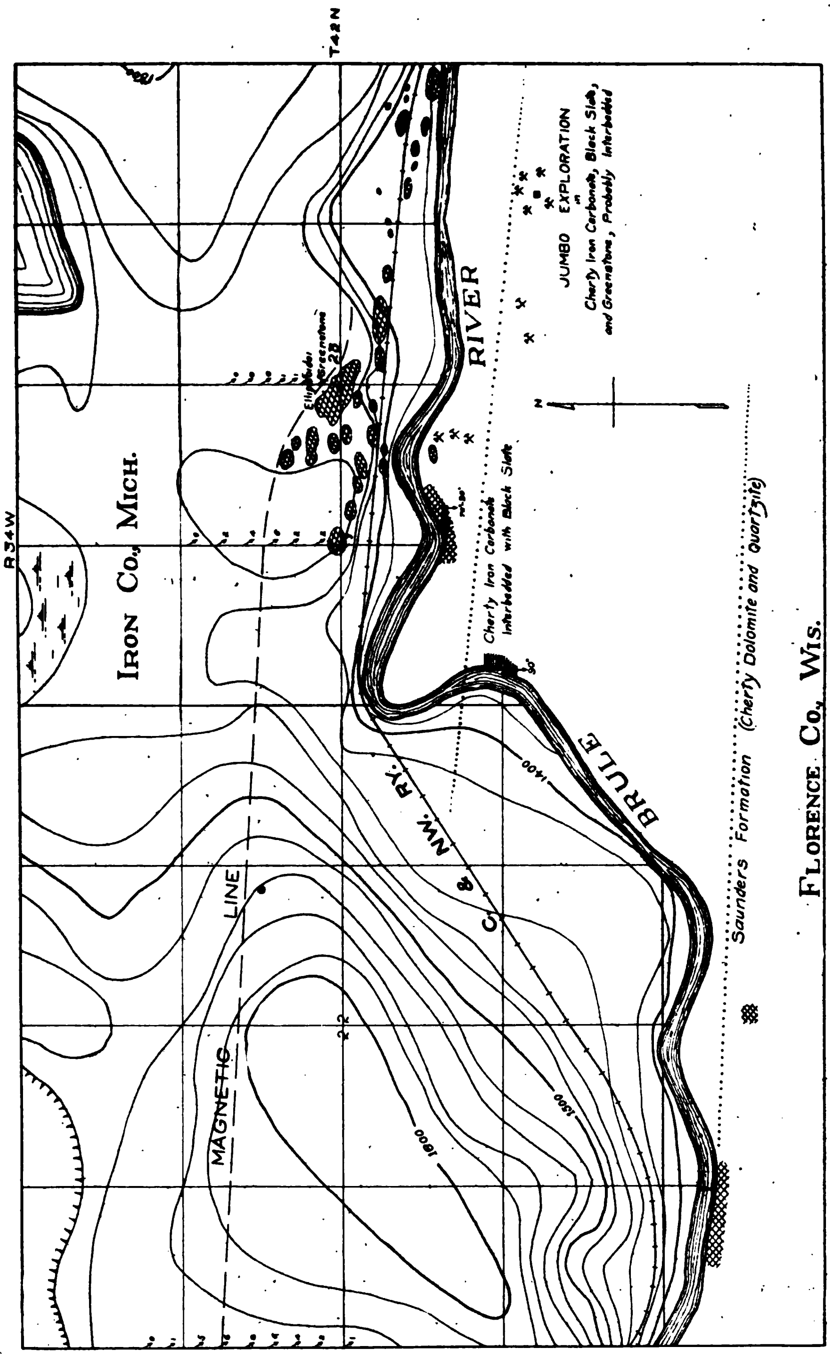


FIG. 3

PLAT SHOWING OUTCROPS ALONG BRULE RIVER NEAR JUMBO EXPLORATION

Vulcan formation strikes a little north of east and seems to dip, on the whole, steeply northward. Farther west this belt has not been traced.

From the Caspian mine northeast to the S. W. 1/4 of the S. W. 1/4 of Section 21, T. 43 N., R. 34 W., drill holes have penetrated what seems to be a more or less continuous belt of Vulcan formation. This belt is about at right angles to the belt along Iron river and with the extension of the Hiawatha belt forms with it a cross. However, we are by no means certain that the line of drill holes in iron formation extending northeastward from the Baker mine to the S. W. 1/4 of the S. W. 1/4 of Section 21, T. 43 N., R. 34 W., indicate a continuous belt of iron formation. The drill holes penetrating ore or ferruginous chert are on the north side of a preglacial valley which, aside from evidence furnished by the drill holes, seems from all available data to cut *across* the strike of the Michigamme series at a high angle.

North of Iron River the strikes are prevailingly about east and west. The Vulcan formation occurs in one main belt extending from the James mine slightly south and east through the Spies and Hall explorations to the N. E. 1/4 of Section 19, T. 43 N., R. 34 W., and slightly north of west to the S. E. 1/4 of the S. E. 1/4 of Section 15, T. 43 N., R. 35 W. The thickness of the bed exposed in the James mine appears to be not above 250 feet, making due allowance for thickening by folding. Black slate forms both foot and hanging walls in this mine. The dip varies from vertical to steeply southward or northward. Other lenses of iron formation occur both north and south of the James belt and its eastward and westward extensions but their importance and extent have yet to be proven by exploration.

ORE BODIES AND PARTICULAR OCCURRENCES OF THE VULCAN FORMATION IN THE CENTRAL AREA.

Zimmerman Mine.—The Zimmerman mine is located in the S. E. 1/4 of the N. W. 1/4 of Section 7, T. 42 N., R. 34 W. The Vulcan formation has been opened on the fourth or 350-foot level eastward from the hoisting shaft about 640 feet. The trend of the formation is on the average from 20° to 25 ° S. W. and the general dip steeply north but locally the dips vary widely due to folding. The iron formation seems to lie between black slate foot and hanging walls which are encountered in the ends of the cross cuts to the north

and south of the main drifts which follow the strike. The north and south walls so far as exposed have no dissimilarities. Frequently the wall slates are very cherty and more closely resemble the Vulcan formation than typical carbonaceous slate. The hoisting shaft is in the Vulcan formation, but an air shaft 40 feet east of it is said to be in black foot wall slates. The major folds are of the drag type and pitch slightly N. E. By reference to figure 4, published by permission of the mine management, it will be seen that the main ore bodies are probably in eastward pitching synclines in the foot wall slates. Thus far in the development of the mine two such ore bodies have been found. The first of these which has been stoped out lay between the second and fourth levels, about 100 feet west of the hoisting shaft. The E.-W. longer dimension of the ore body just above the fourth level was 90 to 100 feet from where it extended upward at an angle of about 70° to a point between the second and third levels. The south wall is black slate, well exposed on the third level, while the north wall is generally soap rock. The boundaries of the ore bodies are not sharply defined by these walls. In many places lean ore and highly decomposed chert intervene between the walls and the rich ore and both east and west the ore grades into ferruginous chert. At nearly a central point between the third and fourth levels the walls dip sharply inward and, it is thought by the superintendent, come together just above the fourth level where the ore body "pinches" out.

The second and largest of the ore bodies has been opened on the 350-foot level about 250 feet S. 60° E. of the former. It pitches slightly northeast. The north wall is black slate but the south wall is lean ore and ferruginous chert. So far as may be judged in the present state of development this ore body seems to lie in an eastward pitching syncline of the drag type, bottomed in slate.

Small unimportant bodies of ore are scattered erratically through the mine and seem to occur in those parts of the formation most highly folded and brecciated.

The thickness of the Vulcan formation in this mine is difficult to determine on account of the character of the folding and uncertainty of discrimination between wall slates and interbedded slates but seems to be not greater than 200 feet.

Baltic Mine.—From the Zimmerman mine the Vulcan formation extends northeastward into the N. W. ¼ of the N. W. ¼ of Sec-

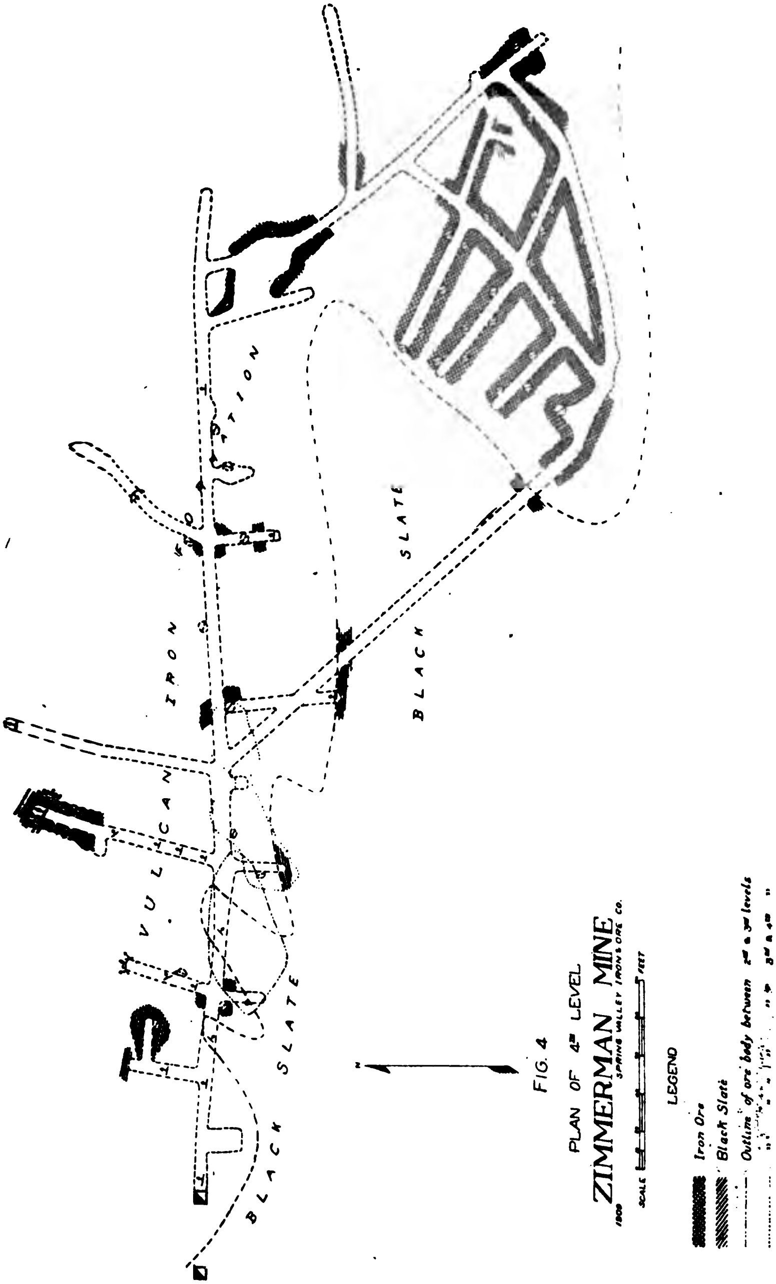


FIG. 4

PLAN OF 4th LEVEL
ZIMMERMAN MINE
SPRING VALLEY IRON & ORE CO.
1908

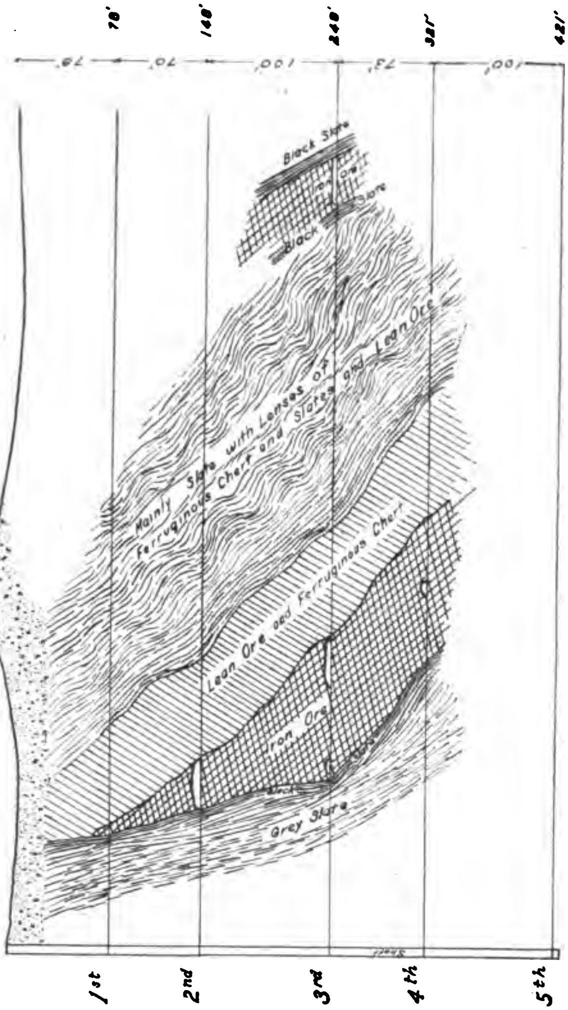
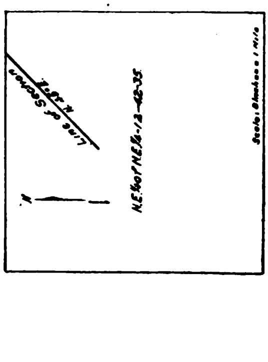


FIG. 5.

SECTION THROUGH YOUNGS MINE.
OCTOBER 1909 HURON IRON MINING CO

Scale 0 50 100 150 200 300 FT



tion 7, where it is opened in the workings of the Baltic mine. From an examination of the plans and sections of this mine through the courtesy of the Verona Mining company, it appears that the Vulcan formation is here folded in two northward pitching synclines carrying the Baltic ore bodies, the synclines being separated by a sharp anticline bringing up the foot wall rocks which are here black siliceous slate as in the Zimmerman mine. The folds are closely compressed which accounts for the general N.-S. strike of the beds and steep inclination from 70° to vertical.

Youngs Mine.—From the Baltic mine the Vulcan formation enters the Youngs location swinging in a curving northwesterly course across the northeast corner of the N. E. ¼ of the N. E. ¼ of Section 12, T. 42 N., R. 35 W., entering, northward, the Fogarty property of the Verona Mining company and thence swinging N. E. into the S. W. ¼ of the S. W. ¼ of Section 6, T. 42 N., R. 35 W.

In the Youngs mine the Vulcan formation is underlain by black and gray slates and dips northeast at angles of from 45° to 65°. Through the courtesy of the management a section is reproduced in figure 5. In this section the main or south ore body lies on a foot wall of black slate which grades downward into gray slates, the probable equivalents of the sericitic schists exposed in outcrop a short distance N. W. of the shaft, extending thence N. W. to the Iron River. The south ore body grades irregularly upward into ferruginous chert and lean ore which is overlain by a thick bed of slates carrying thin iron formation layers locally altered to ore. These rocks are succeeded by a second or north ore body, some 40 to 60 feet thick, with black slate foot and hanging walls. This ore body dips northeast into the workings of the Fogarty mine. Thus in the Youngs mine the Vulcan formation occurs in two separate main lenses, the southern or lower having a thickness of about 140 to 150 feet, the northern or higher a thickness of 40 to 50 feet, the two being separated by about 150 to 175 feet of slate interbedded with layers of the Vulcan.

Fogarty Mine.—Sections through the Fogarty mine (fig. 6) are given through the courtesy of the Verona Mining company. The main ore body of this mine is continuous with the upper or north body of the Youngs. It may be seen by reference to the sections that the foot wall slates of the Youngs mine are not exposed in the Fogarty workings. The character of the rocks west of the Fogarty

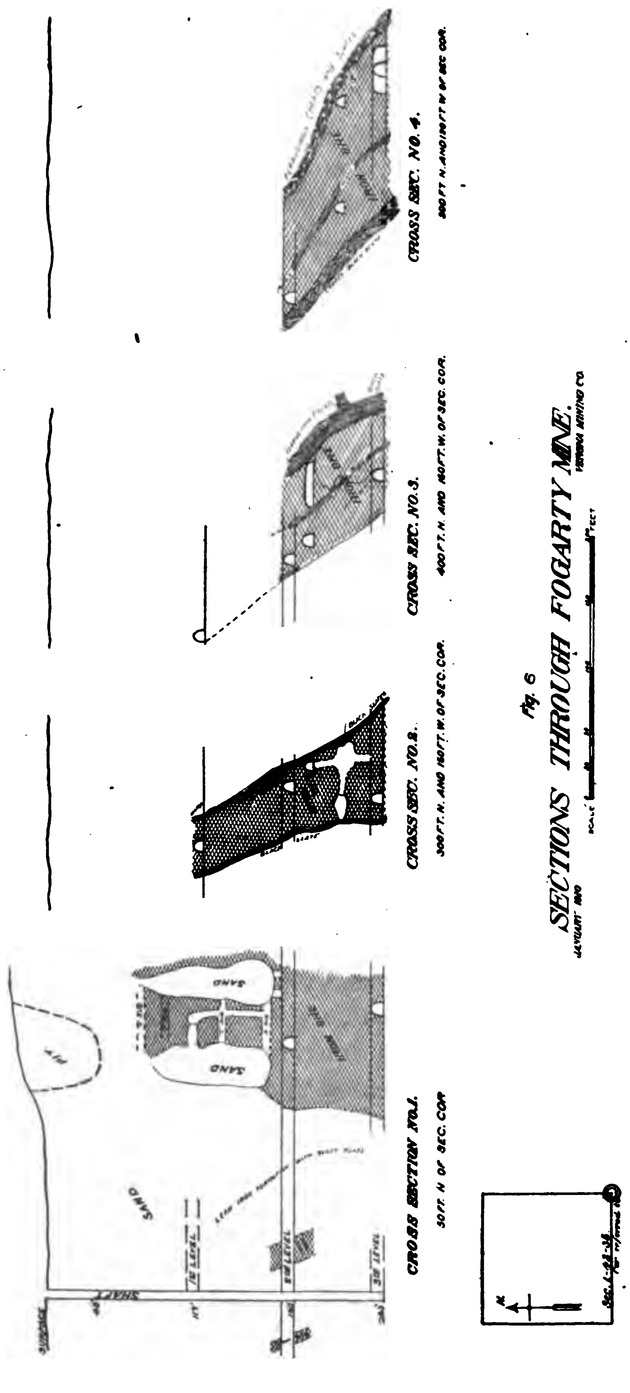


Fig. 6

SECTIONS THROUGH FOGARTY MINE.

workings is shown by a horizontal drill hole extending from a point about 450 feet north and 800 feet west of the S. E. corner of Section 1, T. 42 N., R. 35 W., from the workings of an old shaft, east 715 feet through the north end of the Fogarty mine. This hole penetrated a series of gray, green and red slates interleaved with thin layers of ferruginous chert and bands of ore. West of this hole the workings of the old shaft referred to appear to be largely in black slate, judging from material on the dump. Outcrops of impure cherty iron carbonate, in about vertical position striking N. W., occur in the river bank about 500 feet N. W. Thus it appears that the iron formation developed in the Fogarty mine is underlain on the west by several hundred feet of gray, green, red and black slates, carrying iron formation layers of varying slight thicknesses. It will be seen by reference to figure 6 that the various sections which are taken across the strike of a continuous stratigraphic horizon in the Fogarty mine do not closely correspond. Slate occurs in discontinuous lenses in the ore body and on both its foot and hanging walls as well as in the leaner parts of the formation. The occurrence of ore in this mine is evidently not dependent on the presence of impervious slate layers although the local favorable influence of these on ore concentration is apparent on examination of the underground workings. The Vulcan formation exposed in the Fogarty mine has a maximum thickness of about 300 feet which corresponds well with the Youngs mine section.

Berkshire Mine.—The Vulcan formation on the N. W. ¼ of the S. W. ¼ of Section 6, T. 42 N., R. 34 W., is exposed in the workings of the Berkshire mine. The strike is approximately E.-W. and the dip steeply south. From the workings of the mine the formation probably extends east into the Corry exploration, where the Verona Mining company has proved by drilling the occurrence of ore bearing iron formation, and west into the Cottrell exploration of the Oliver Mining Company. The drill cores of the Corry exploration indicate a much lower dip than prevails in the Berkshire mine. Just what connection there is between the Berkshire and Fogarty belts is as yet a matter of conjecture. They are probably in the same horizon but the possibilities of folding, faulting and truncation by erosion are such that the facts of occurrence might be explained on alternate hypothesis involving several dif-

ferent combinations of these factors which it seems unprofitable to discuss until data are more complete.

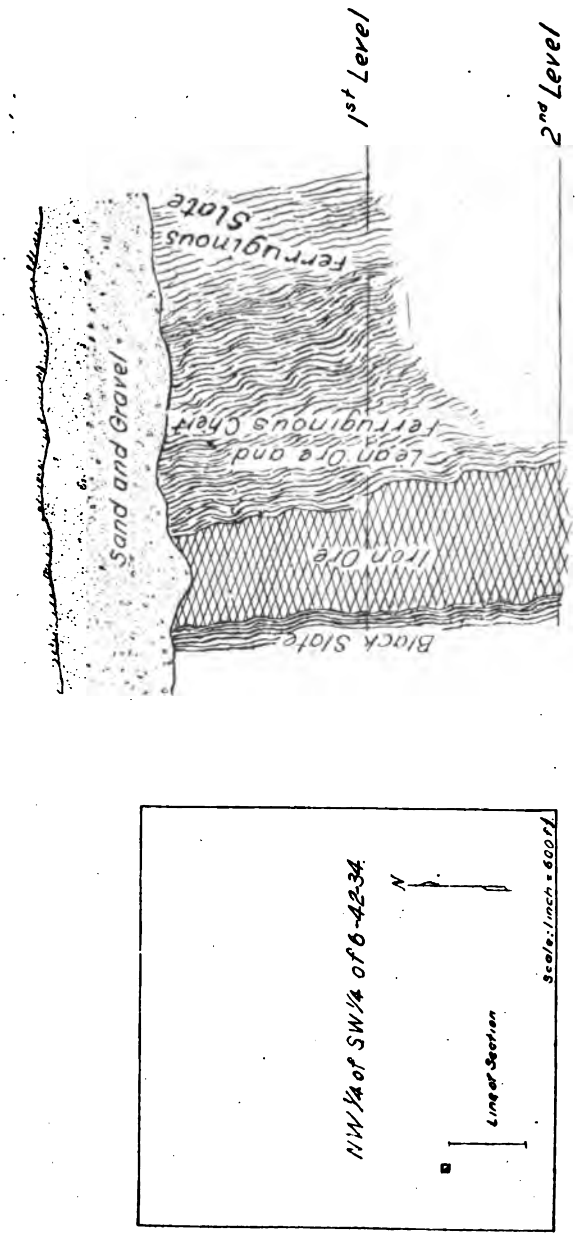


Fig. 7

SECTION THROUGH BERKSHIRE MINE.

SEPTEMBER 1909 BRULE MINING CO.

Scale 0 50 100 150 200 Feet

The main structural features of the Berkshire ore body are shown in figure 7 by permission of the Brule Mining company. In the west end of the mine the ore body lies on a wall of siliceous black slate grading into ferruginous chert toward the east. Whether this slate is basal to the Vulcan formation or is within it is not known but the latter is probably the truth. The ore body, from 50 to 80 feet thick, grades upward and laterally into ferruginous chert which is overlain by massive ferruginous slates. The top of the ore body is marked by a depression some 10 to 15 feet deep, probably the result of downward slump of the ore due to leaching of silica during concentration.

Caspian Mine.—Northwest of the Berkshire mine the Vulcan formation is unexplored to the Caspian mine. In this mine the formation strikes N. about 60° W. and is in vertical position. It has a maximum thickness of from 300 to possibly 400 feet, making due allowance for thickening by folding. In places the formation is entirely altered to iron ore. The east and west walls in this mine are not usually well defined. Many of the cross cuts have been discontinued near the limits of the ore body. The most common wall rock is black slate, in many places highly graphitic, in others cherty and siliceous. Slates, more or less ferruginous, and ferruginous chert are common wall rocks. Cross sections drawn by the writer from mine plats are shown in figure 8 through courtesy of the Verona Mining company. North of the Caspian, ore bearing Vulcan formation occurs in the Tully exploration in the S. W. ¼ of the S. E. ¼ of Section 36, T. 43 N., R. 35 W. It is believed by many that the Vulcan of the Caspian and Tully properties is connected across the N. W. ¼ of the N. E. ¼ of Section 1, T. 42 N., R. 35 W. Such connection is probable in view of the strike of the formation in the Caspian and the results of exploration on the N. E. ¼ of the N. W. ¼ of the section lying between the Caspian and the Dober properties.

The Barrass Mine.—North and east of the Tully, the S. E. ¼ of Section 36, T. 43 N., R. 35 W., so far as exploration has shown, is underlain by Vulcan formation which extends north into the N. E. ¼ of the section, as shown in the workings of the Barrass mine and drill holes one-quarter of a mile north of it, and east into the S. W. ¼ of Section 31, T. 43 N., R. 34 W., where it is opened in the Baker mine.

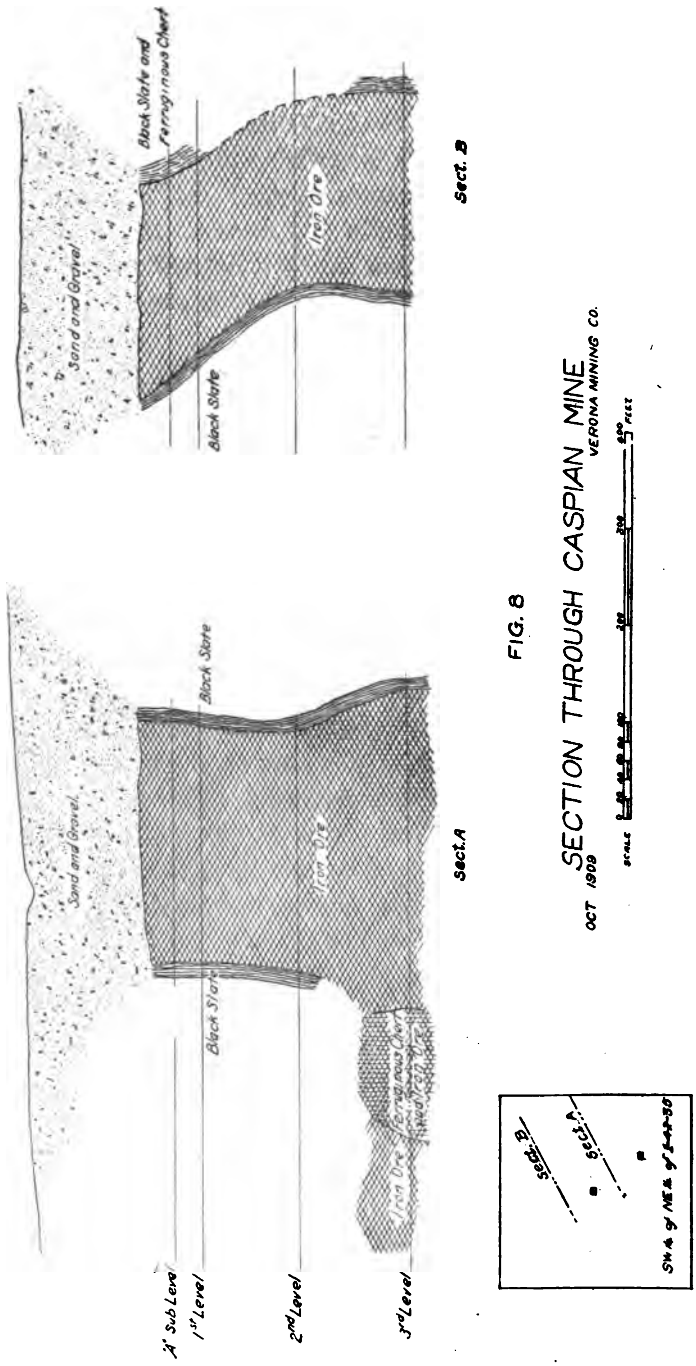


FIG. 8

SECTION THROUGH CASPIAN MINE

OCT 1909

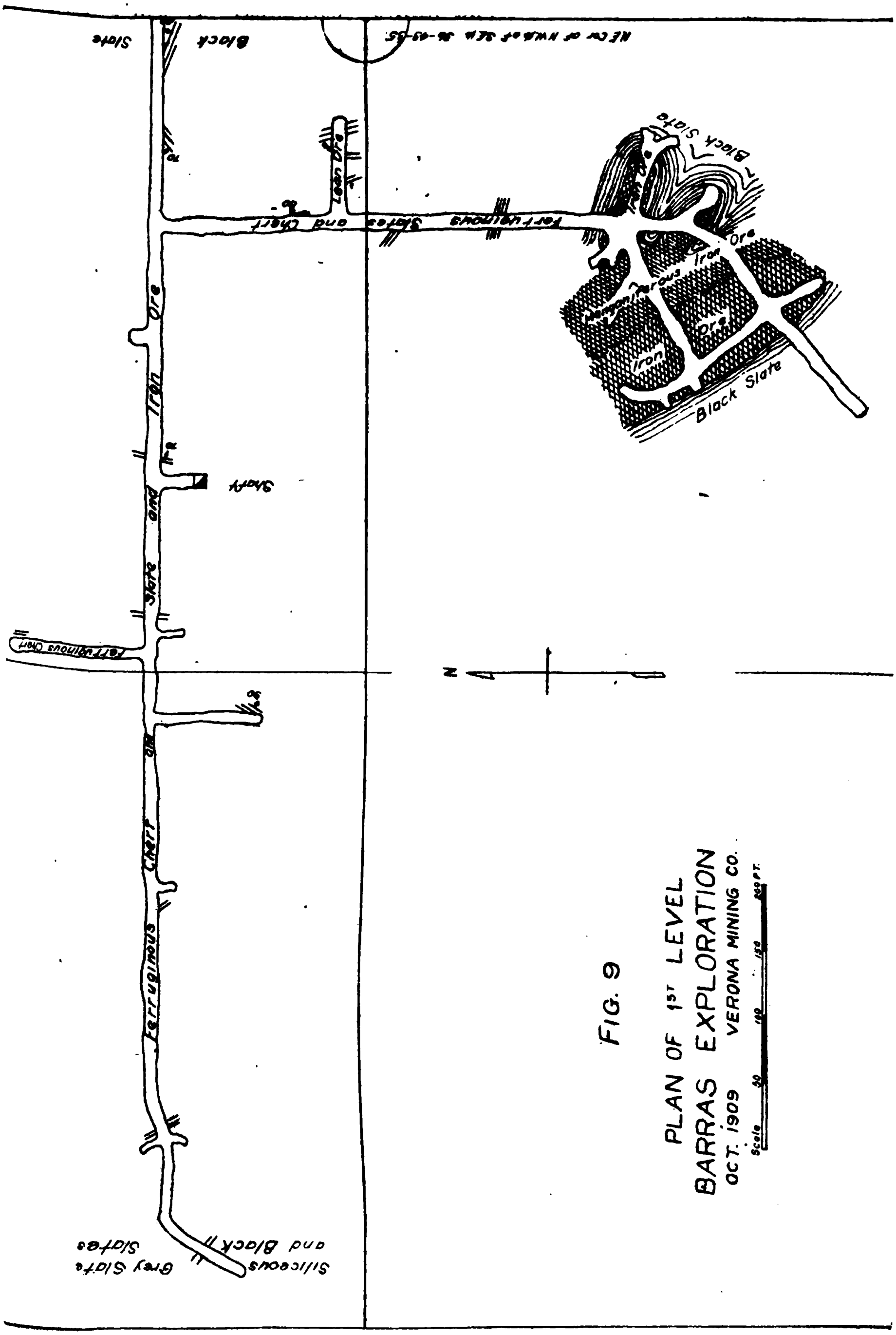


FIG. 9
PLAN OF 1ST LEVEL
BARRAS EXPLORATION
OCT. 1909 VERONA MINING CO.

A sketch of the first level of the Barrass mine is shown in figure 9 by permission of the Verona Mining company. It will be seen by reference to this sketch that the general trend of the formation is N. W., although locally the strike varies widely. The dip is about vertical on the whole but varies from place to place as much as 35°. The bedding is twisted and contorted to an extreme degree in some parts of the workings. The main ore body thus far discovered seems to lie on a folded foot wall of black slate and probably pitches northwest but work has not progressed far enough to disclose the exact structural relations. This deposit is notable for its high content of manganese. The manganese occurs as black oxide intimately mixed with hematite and is most abundant in the northeast side of the ore body. Caving prevented an examination of this deposit by the writer and we are indebted to Mr. I. N. Woodworth for the notes here given and also for the following partial analysis of an average sample of the hard and soft manganiferous ore which is published through courtesy of the Verona Mining company.

Partial analysis of average sample of hard and soft manganiferous iron ore frôm the Barrass mine:

Iron	23.20 %
Phosphorous	.434
Manganese	26.86
Silica	5.60
Aluminum	3.60
Sulphur	.136
Calcium oxide	2.15
Magnesium oxide	4.84
Volatile	13.00

The Baker Mine.—The workings of the Baker mine disclose a highly contorted, brecciated and shattered mass of ferruginous chert and ore. The writer was unable from careful examination of the workings to come to any conclusion regarding the general structural relations. Slate walls are not present and the bedding of the iron formation is so extremely contorted and brecciated that

attempts to work out the general attitude of the Vulcan formation proved futile. The ore bodies are scattered in pockets of irregular shapes through the ferruginous chert into which they grade by decrease in iron content and rise in silica. Adjacent to the ore bodies the ferruginous chert is in most cases highly decomposed, the chert being frequently so friable as to crumble readily between the fingers, in which state it is called "sandstone" by the miners.

The Isabella and Dober Mines.—The Isabella mine adjoins the Dober on the north. The two properties are operated by the Oliver Mining company from the shafts of the Dober. The general trend of the Vulcan formation in both mines is northeast and the dip northwest. In the Dober mine the dip is about vertical near the surface but becomes less steep in depth and from the fourth level downward averages between 40 and 50 degrees. The depth of the Dober workings is 600 feet but ore is known to occur to a depth of at least more than 150 feet below this level.

The relations of the Dober ore deposits to wall rocks are interesting and instructive. In the lower levels black slate and graphitic chert envelopes the ore body on the north, east and west and black slate occurs on the south wall. In the words of Captain Duff "one cannot get out of the Dober ore body without going through black slate." It was suspected that these relations are in part due to replacement along the bedding of iron formation by black slate and graphitic chert. A careful examination of the workings under the guidance of Captain Duff with this idea in mind soon established the truth of the supposition. In one place near the end of a cross cut on the fifth level rich ore grades into lean ore carrying carbonaceous material and this into black graphitic slate in a distance of three feet the bedding being continuous and unbroken from the ore into the black slate. Similar gradations of ferruginous chert into siliceous black slate occur at other places in the mine.

It has already been stated that the chief obstacle encountered in working out structure in the Iron River district lies in the difficulty of identifying stratigraphic horizons because of their ever varying changes in character from place to place in the direction of strike. The instance cited above is an illustration of the rapidity with which such changes often occur. This often leads to confusion in mine mapping since it is common in this district to include all dark or black rocks in the term black slate. The occur-

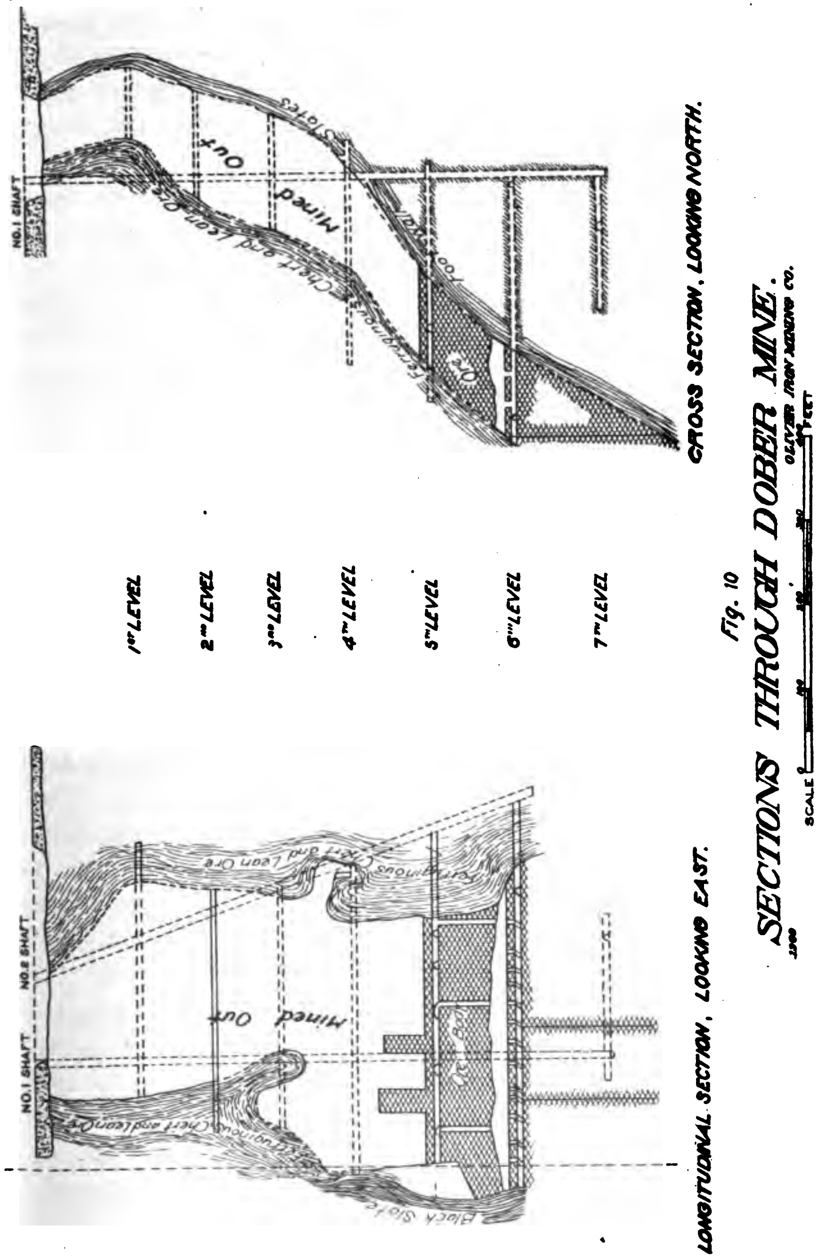
rence of graphitic matter is, however, not confined to the slates. The Vulcan formation is often so highly charged with carbonaceous matter that it becomes very dark in color or even black. Mr. Connibear, of the Cleveland Cliffs Iron Co., states that he has encountered, in drilling, rocks having all of the appearances of graphitic black slate but which contain by analysis from 20% to 25% of iron. There is no doubt that much of the black slate of this district is heavily charged with iron in the form of oxide and carbonate although pyrite is the most conspicuous iron bearing mineral.

While in the Dober mine iron ore and ferruginous chert grade laterally and vertically into black slate and black chert, in many places the ore lies with sharp contact on black slate the bedding in the two rocks being parallel. South and east of the Dober workings are interbedded black, gray, and green slates carrying thin bands of jasper and cherty iron carbonate.

Sections through the Dober mine, drawn by Mr. D. A. Hellberg, are given in fig. 10 through courtesy of the Oliver Mining company.

The Isabella workings are northeast of the Dober. The Vulcan formation in the Isabella is separated on the fifth or 500-foot level from the Vulcan in the Dober by from 250 to 300 feet of "black rock" and black slate which, as in the Dober, seems to completely enclose the ferruginous chert and ore on this level. Gradational phases between ferruginous chert and black graphitic slate and chert are shown here as in the Dober workings. Formerly the Isabella was worked as an open pit. A "chimney" of ore was worked from the surface downward to a depth of several hundred feet but drilling shows that this body seems not to be connected with the ore in the lower levels now worked from the Dober shafts. The rocks exposed in the walls of the open pit are mainly lean iron formation. Gray slates occur on the southeast side and these are succeeded by graphitic black slate which crosses the pit from northeast to southwest. The ore body seems to have lain on the black and gray slate with steep pitch to the northwest and was overlain by ferruginous chert.

The Chatam Mine.—The Chatam mine is operated by the Brule Mining company. It is northwest of the Isabella on the N. E. ¼ of the S. E. ¼ of Section 35, T. 43 N., R. 35 W. The property is crossed from north to south by Iron river and is being developed through two shafts, No. 1 west of the river, and No. 2 east of it.



CROSS SECTION, LOOKING NORTH.

LONGITUDINAL SECTION, LOOKING EAST.

Fig. 10

SECTIONS THROUGH DOBER MINE.

,s of shaft No. 1, which has reached a depth of 400 n formation trends north and south and dips steeply ime of the writer's visit two bodies of ore were being out 300 feet south of the shaft and the other between l the north boundary of this property. The pitch of es is in the direction of dip of the iron formation and from the fourth level to the surface. The ore grades ng the strike of bedding and across it into lean ore and chert.

orkings of shaft No. 2 the general dip of the Vulcan is steeply west and strike about N. and S. Ore bodies e northern and southern ends of the workings, one about north of the shaft, reaching surface under the highway ther at the south pitching apparently south or southwest. ions between ore and adjacent rocks are the same here workings of No. 1 shaft.

Iiawatha Mine.—South of the Chatam mine a belt of iron on swings westward with steep north dip through the y of the Hiawatha mine. In this mine the Vulcan is over- the north or hanging wall side by black graphitic slate and hert but the foot wall rocks are not exposed, the south cross eing in iron formation often but slightly altered. On the e in a drainage ditch on the south side of the small ravine south of the shaft are exposed an interbedded series of dark wacke, black slate, and ferruginous slate and chert (see p.)). These rocks underlie the iron formation opened up in the watha workings. The structure of the Hiawatha belt is by a aber of engineers interpreted as a closely compressed syncline ching westward toward the main "Iron river trough." The iter, after a study of the mine workings and mine plats, through e courtesy of the Munro Iron Mining company, is not able to ther affirm or deny the correctness of this interpretation. There s absolutely no evidence of a synclinal structure to be adduced rom the *facts* of structure in the Hiawatha mine. The north or hanging wall is fairly well defined, the south or foot wall is not penetrated by the mine workings. The underlying rocks exposed at the surface are not lithologically closely similar to the black slate and chert of the hanging wall but they *may* nevertheless be stratigraphically equivalent. Until some evidence to the contrary

is found the Hiawatha belt must be interpreted as a northward dipping monocline as indicated by *known* facts of structure.

The occurrence of ore in the Hiawatha mine is similar to that in Chatam No. 1. The longer dimensions of the ore bodies are generally in the plane of bedding of the iron formation. In some

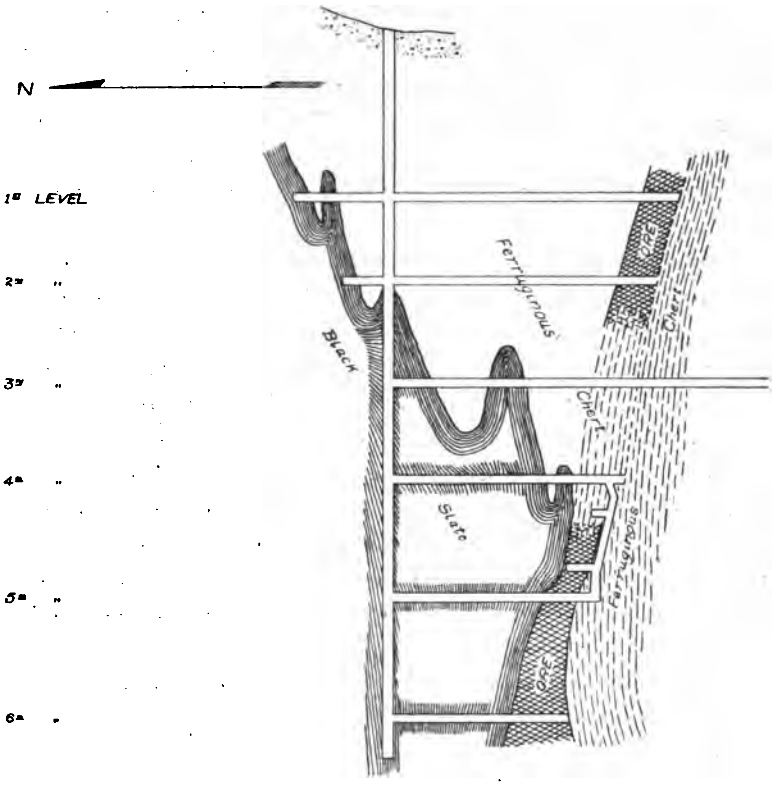


FIG. 11

SECTION THROUGH MAIN CROSS-CUTS OF HIAWATHA MINE.

places they lie against the black slate and chert hanging wall, in others they are overlain and underlain by lean ore and ferruginous chert and pass by gradation in the plane of bedding into these rocks. In some places the ore is underlain within a few feet by iron formation only slightly altered. While the iron formation is generally contorted by minor folding, the ore bodies do not seem

to have close relation to folds but must be considered as irregular concentrations in a steeply dipping belt of iron formation. A cross section through the Hiawatha mine is shown in figure 11 through the courtesy of the Munro Iron Mining company.

The Riverton Mine.—North of the Chatam is the Riverton mine on the N. E. ¼ of the N. E. ¼ of Section 36, T. 43 N., R. 35 W. The Riverton mine is the oldest in the district and marks the site of the first discovery of iron ore by Harvey Mellen in 1854. It was formerly worked as an open pit to the second level. The mine is not in operation at the present time. The following notes are the result of a study of the rocks exposed in the open pits and of mine plats furnished through the courtesy of the Oliver Mining Company.

The general trend of the Vulcan formation is north and south, the dip steeply west. It is underlain on the east by chloritic-biotitic-quartz slates and schists, in places more or less ferruginous. These constitute the "green rock" appearing in the mine plats. With the exception that the term "green rock" has been changed to chloritic-quartz schist figures 12 and 13 are reproductions of drawings furnished by the Oliver Mining company. The strike of the magnetitic-chloritic-sideritic slates exposed on the top of Stambaugh hill would carry them under the iron formation of the Riverton mine. With the exception of magnetite these rocks are mineralogically similar to the "green rock" of the Iron River mine and are doubtless equivalent to it.

Two separate, main ore bodies occurred in the Riverton mine. The lowermost lay on the foot wall of chloritic-quartz slate and seems to have been completely separated from the upper one by an intervening belt of black slate. It was bottomed on the fifth level in ferruginous chert and "jasper." The upper body was underlain and overlain by black slate and, like the former, seems to have bottomed in ferruginous chert and jasper. Both ore bodies had a western pitch in direction of dip of iron formation. These relations are clearly shown in figures 12 and 13.

From the Riverton mine the Vulcan formation extends northward into the workings of the Miller exploration on the S. W. ¼ of the S. W. ¼ of Section 25, T. 43 N., R. 35 W. The formation is here said to bear ore. The property is undeveloped and the workings are now filled with water.

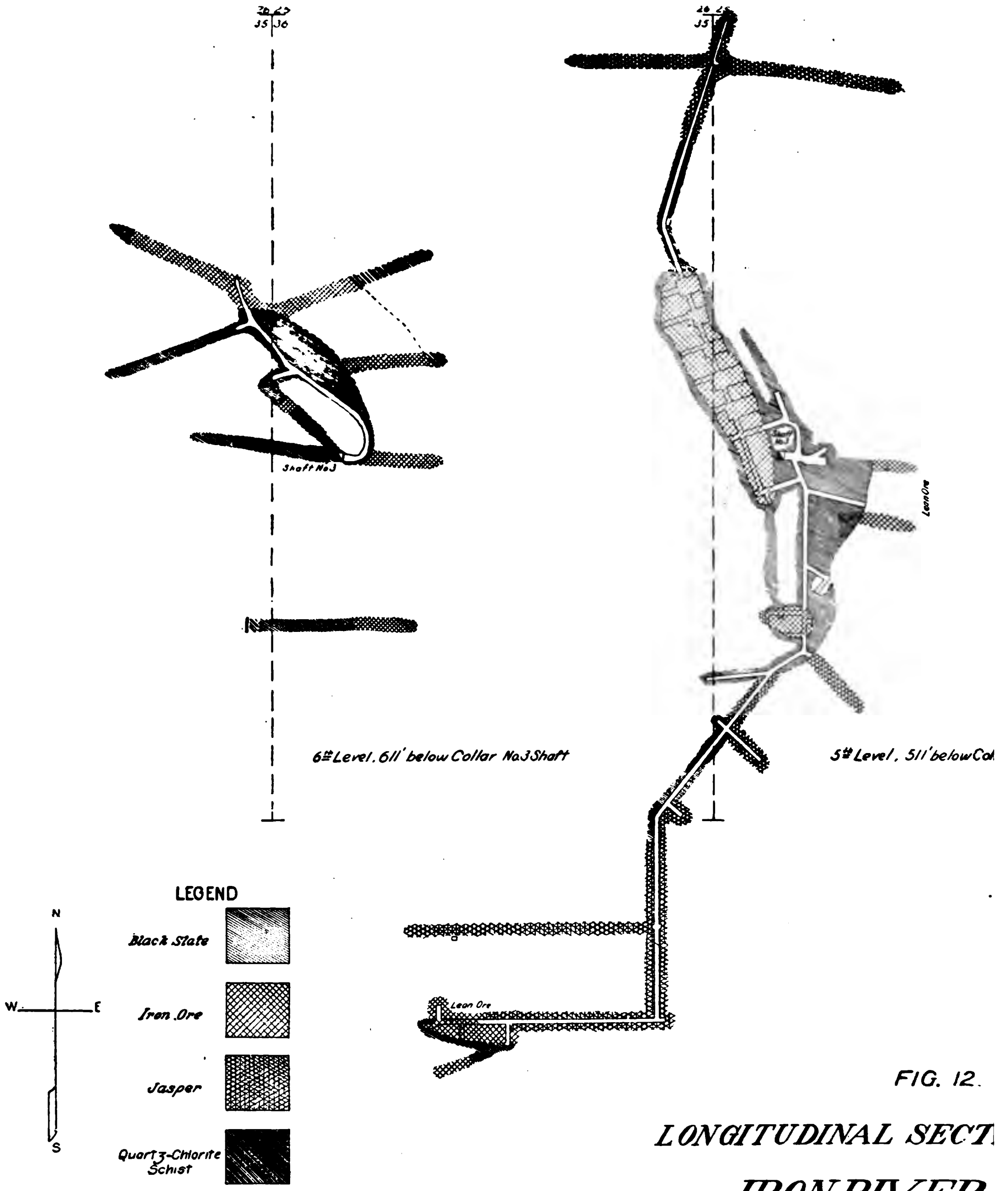


FIG. 12.

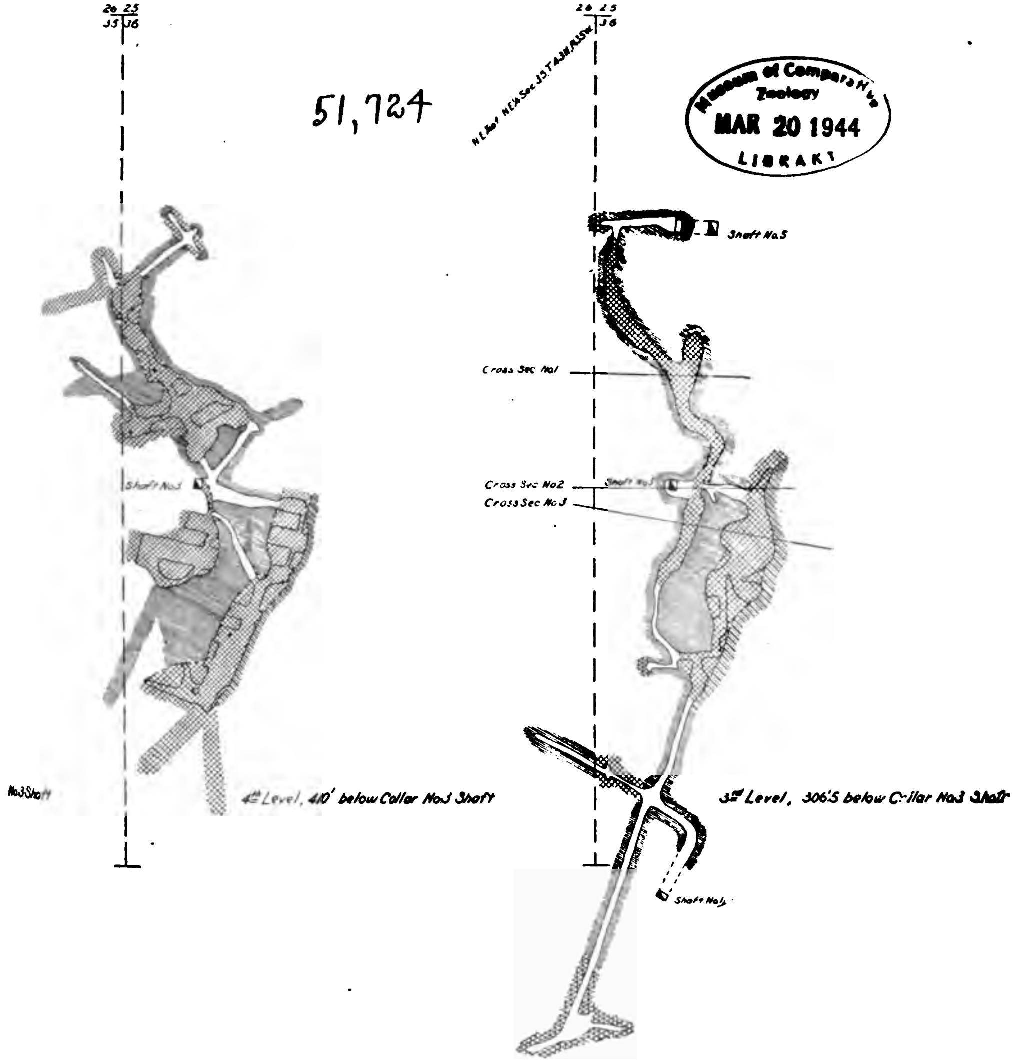
LONGITUDINAL SECT

IRON RIVER

OLIVE

Scale

51,724



...ONS THROUGH,

...MINE.

...RON MINING CO.

...300 Feet

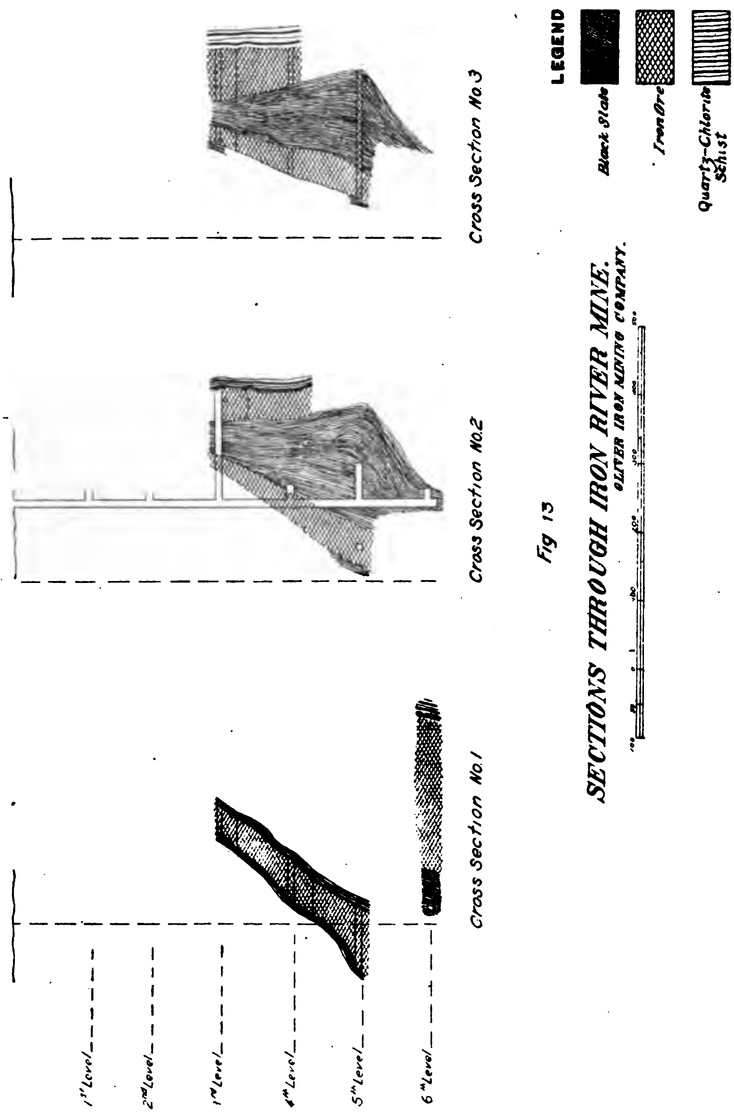


Fig 13

SECTIONS THROUGH IRON RIVER MINE.
OLIVER IRON MINING COMPANY.

The Sheridan Mine.—The Sheridan mine lies west of the Miller exploration. It was an early producer but has not been operated since 1896. Considerable exploratory work has been recently done which, with surface exposures, gives a fairly good idea of the succession. The trend of the rock seems to be a little west of north. On the west side of the property is a belt of black slate which is

succeeded eastward by a variable thickness of cherty iron carbonate grading farther eastward into ferruginous chert which is in turn followed by another belt of black slate. Brecciated jasper and chert succeed the second black slate belt and in this material is sunk the open pit of the old Sheridan mine. Still farther east is a third belt of black and gray slate which extends southward into the Riverton property. With this succession of rocks on a single 40-acre tract the impossibility of separating slate and iron formation in mapping is again well illustrated.

Beta and Nanaimo Mines.—The Beta and Nanaimo mines are among the earliest producers. They are not now in operation and the workings are inaccessible. Beyond the fact that the Vulcan formation is steeply dipping here as elsewhere and trends in a general northwesterly direction the writer has no information regarding the structure in the Vulcan formation in these mines.

James Mine.—The James mine is in the N. ½ of the N. E. ¼ of Section 23, T. 43 N., R. 35 W., about 1½ miles north of Iron River. The Vulcan formation is well opened up on four levels to a depth of 400 feet. On the third level the workings extend from 80 feet east to 1,380 feet west of the shaft. The main drift on this level follows the strike of the iron formation slightly west of north. The rocks are folded and contorted in a bewildering manner. Perhaps a majority of the folds have a westward pitch. The general structure is a monocline dipping from vertical to steeply north or south. Cross cuts to the north and south penetrate black slate in both directions. In general the ore bodies in this mine occur in pockets and lenses of varying dimensions, grading into ferruginous chert, as in the Zimmerman, Hiawatha, Baker and Chatam mines, but the larger ones lie on walls of black slate. None of the ore bodies thus far mined are known to reach the surface. Evidence of gradation along the bedding of iron formation with black slate and black chert is plentiful here as in the Dober, Isabella and other mines and presents a great obstacle to accurate structural mapping. When these rocks are encountered in cross cuts work is usually suspended.

Perhaps a close detailed study of the mine would show that the ore bodies are more or less closely related to the westward pitching folds. This seems to be true in at least one notable instance. From a drift a few hundred feet west of the shaft on the 400-foot

level a north cross cut penetrated 145 feet of ore lying on a steeply northward dipping black slate wall, and grading northward into ferruginous chert and ore which at 120 feet north of the ore body is cut off by a northward dipping wall of black slate. The total width of the iron formation in this cross cut is 260 feet, which gives a thickness of 250 feet normal to the bedding. The ore body follows the south slate wall upward to the third level and passes over a wedge of black slate as shown in a sub level about 40 feet above with a total width of 230 feet and descending on the south side of the slate wedge with a thickness of 116 feet on the third level. In the sublevel where the crest of the black slate wedge is encountered the banding in the ore shows a perfect anticlinal fold pitching west. A cross cut on the third level 200 feet west of this place and 400 feet lower does not cut the black slate. The relations are shown in section in figure 14 drawn by Mr. A. J. Myers of the Pewabic Mining Co.

South of the James mine about three-eights of a mile is the Konwinski exploration in which is proven by drill holes and two exploratory shafts a belt of iron formation at least nearly half a mile long with strike slightly north of west parallel to the James belt. So far as known the rock occupying the interval between the James and the Konwinski belts is mainly black slate. According to the mine captain, pumping from the western Konwinski shaft does not affect the water level in the shaft about 800 feet slightly S. W. and this is taken by him as evidence that the two shafts are separated by an impervious slate belt.

The James belt is opened on the west by the Gleason exploration in the N. E. ¼ of the N. W. ¼ of Section 23 and drilling for a distance of some one-half to three-fourths miles farther west is reported to have proven the extension of the James belt thus far in this direction.

The Spies exploration of the Verona Mining company between 600 and 700 feet slightly southeast of the James shaft is in ore bearing **Vulcan formation and** eastward on the strike of the Gleason-James-Spies belt in the N. W. ¼ of Section 19, T. 43 N., R. 34 W., many drill holes of the Hall exploration of the Florence Mining Co. penetrate ferruginous chert and ore. From known facts of general structure it seems probable that the Hall exploration is on about the horizon of the Chicagon exploration, but it

by no means follows that these explorations are connected by a continuous belt of iron formation since it is not improbable that the Vulcan formation is discontinuous, being replaced along the horizon by slates and possibly to some extent by greenstone.

THE NORTHERN AREA.

MORRISON CREEK BELT.

A narrow band of ferruginous chert and sideritic slate disclosed in the dumps of numerous test pits follows the sixteenth line forming the north boundary of the south half of the S. W. ¼ of Section 24, T. 44 N., R. 35 W. A few outcrops of sideritic slates occur on the banks of Morrison creek in an east-west line with the pits. The dip is vertical or slightly northward. The iron formation at Morrison creek is closely associated with black carbonaceous slate with which it is underlain and probably interbedded. Adjacent to the iron formation on the north, and stratigraphically above it, is sericitic schist, a metamorphosed equivalent of the graywacke exposed to the east and north in numerous outcrops. Southward the slate seems to be underlain by volcanic greenstone which outcrops for about a mile along the line between townships 34 and 35, R. 44 N.

THE ATKINSON BELT.

Southwest of Atkinson Vulcan formation occurs in a double belt separated by a belt of volcanic greenstone-breccia. (See figure 15.) The dip of the greenstone and associated iron formation and slate here seems to be uniformly northwest at an angle of about 55°.

It will be interesting to consider in some detail the Atkinson section since the interbedded relations of the various rocks in the Michigamme slate are here best exhibited. The southernmost rock is mainly black slate carrying considerable but varying amounts of carbonaceous matter, in places becoming cherty and ferruginous, especially toward the top of the horizon, where it gives place to a thin iron formation, according to plats of the McColman exploration furnished by the Verona Mining Co., about 80 feet thick. The Vulcan formation at this horizon has not been followed beyond the workings of the McColman exploration. The iron formation, as shown by an examination of the rocks on the dump of the Mc-

Colman shaft, includes hard, limonitic iron ore, ferruginous chert and brownish and gray banded sideritic slate. The slaty phases are sericitic, chloritic, and biotitic, and in one case abundant titanite was found. The ore occurs in lenses in the slaty phases of the formation. From an inspection of the Verona Mining Co. plats it appears that the highly sericitic-biotitic-chloritic slates are abundant just under the overlying greenstone.

The greenstone belt extends from the N. E. corner of Section 18, T. 44 N., R. 35 W., northward into the S. W. 1/4 of the N. E. 1/4 of Section 9 of the same township and doubtless further in both directions where exposures are lacking. Its thickness seems to vary from 700 or 800 feet up to possibly 1,400 or 1,500 feet at the northeast end. In places this rock is very schistose, but generally its original agglomeratic structure is plainly observable. Brecciation is common but resulting structures can usually be discriminated from its original agglomeratic structure, the fractures of the former cutting indifferently across the latter. The rock is extremely altered. Weathered surfaces have the green colors of chlorite and epidote and show abundance of secondary calcite and dolomite filling fracture planes.

The greenstone is overlain by a belt of ferruginous slates and cherts becoming more siliceous in the upper horizons. Near the underlying greenstone black carbonaceous slates are found but these seem to be less prominent in the higher horizons which are composed dominantly of very lean ferruginous granular chert. Only one natural exposure is known, but numerous pits and a few drill holes disclose the character of the formation. This belt is less than a quarter of a mile wide. North of it sericitic slates are found and these in turn grade northward into micaceous schists and graywackes which are the dominant rocks in the northern part of the Iron River district.

While little is known of the extent of the Vulcan beds in the Atkinson district it should be noted that southwest, on the strike of these beds, in the S. E. 1/4 of Section 14, T. 44 N., R. 36 W., lean, ferruginous, white, granular, cherty beds of the character of similar ones at Atkinson are associated with black slate and overlain by micaceous graywacke. Similar, white, granular chert occurs on the strike of the Atkinson horizon in the bed of Paint river in the S. W. 1/4 of the N. E. 1/4 of Section 1, T. 44 N., R. 35 W. While

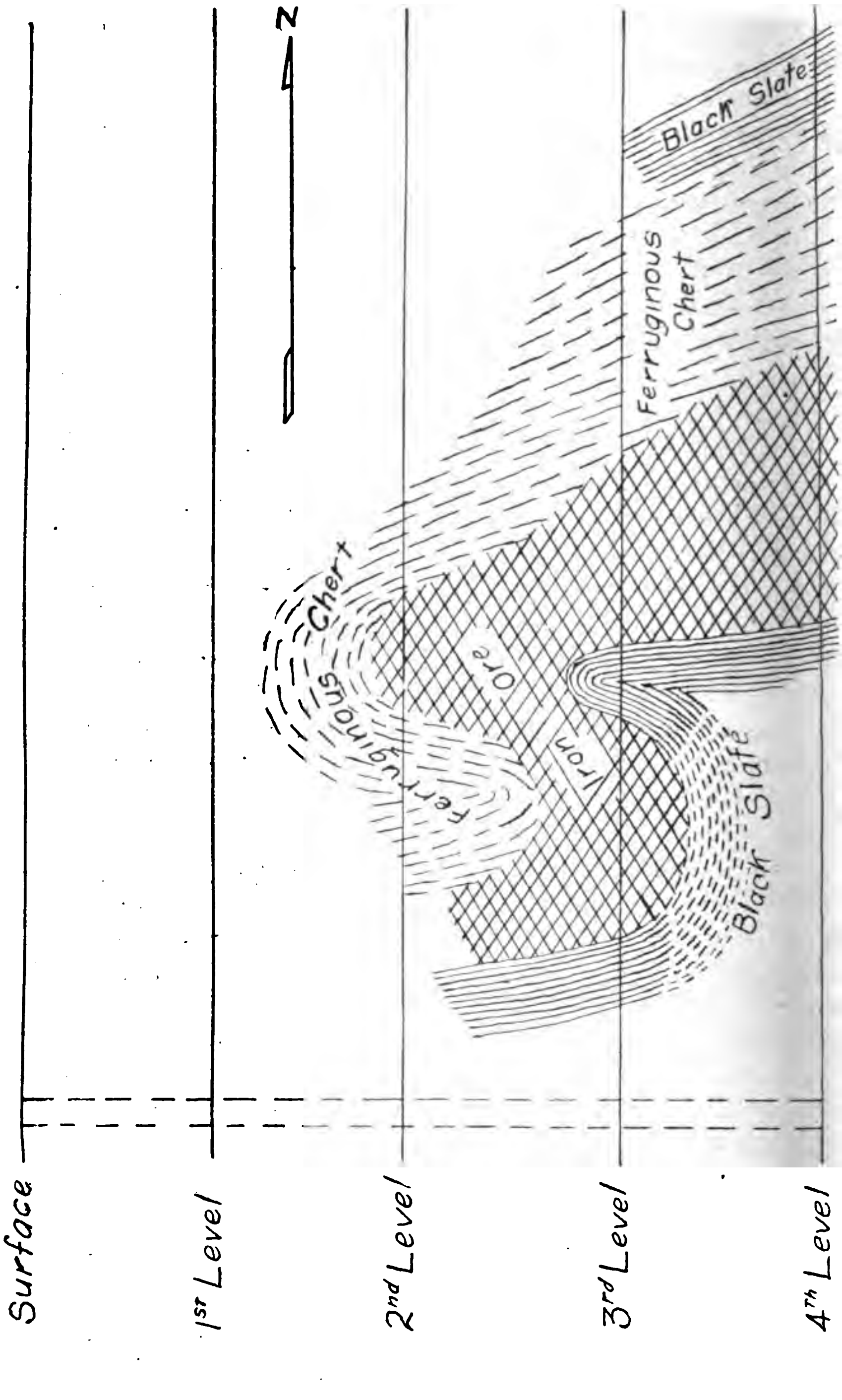
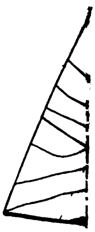


FIG. 14 SECTION THROUGH JAMES MINE



these two occurrences seem to be at about the horizon of the Atkinson beds, it should not be inferred that iron formation is continuous from one locality to the other along this indicated belt. The probabilities are that the reverse is true.

SLATES AND GRAYWACKES OF THE MICHIGAMME SERIES.

Slates and graywackes and their metamorphosed equivalents form the bulk of the Michigamme series in which the Vulcan iron formation occurs. In the northern part of the district graywacke and graywacke-slate and their metamorphosed equivalents are the dominant rocks. They are well exposed in the valley of Paint river from which they have received the name Paint Slates. The rocks associated with the Vulcan formation in the central or ore producing part of the district are, on the whole, finer grained and comprise a variety of phases including the black carbonaceous slate, closely associated in occurrence with the Vulcan formation, and gradational phases to graywacke and iron formation.

A study of these slates throws some light on the conditions of deposition of the iron bearing rocks and also explains some of the difficulties encountered by the prospector and the geologist in correlating stratigraphic horizons of one area with horizons in adjacent areas.

CHARACTER OF THE MICHIGAMME (HANBURY) SLATES ASSOCIATED WITH THE VULCAN FORMATION.

(1). *Black Slate.*—The term *black slate* in local usage covers all slaty rocks of black or very dark color. Carbonaceous matter, responsible for the dark colors, is the characteristic constituent and varies from a small amount, which may be present in any of the slates, to perhaps 10% of the weight of the rock. The typical black slates are soft, coal black, pyritic, and contain perhaps between 5% and 10% of carbon. A specimen from the south or hanging wall on the third level of the James mine, called "graphite" by the miners, was selected for analysis because of its apparently high content of carbon. At the point where the specimen was taken the transition from ferruginous chert to black slate is abrupt and the sample for analysis was broken from the wall of a drift only a few inches from the contact.

ANALYSIS OF BLACK SLATE FROM THE JAMES MINE.[1]

SiO_2	66.63
Al_2O_3	2.48
Fe_2O_3	7.80
FeO	1.58
CaO	.25
MgO	.29
S	7.06
C	8.64
CO_2	.83
H_2O	3.80
Total	99.36

Compared with the composition of typical slates and shales this rock is markedly deficient in alumina and the alkalies, the percentage of these constituents corresponding to 66.63% of silica in typical mud slates and shales being about balanced in this rock by the carbon and sulphur content. The carbon occurs mainly in uncombined amorphous condition, the sulphur in combination with iron to form pyrite or marcasite, the latter minerals being invariably present in abundance in the black slates.

When exposed to the air in waste piles the iron sulphide rapidly oxidizes, the iron to hematite and the sulphur to sulphur dioxide. Burning waste piles are a common sight in the Iron River district. The reaction which may be written:

$$2FeS + 11O = Fe_2O_3 + 4SO_2$$

takes place with liberation of heat which operates to raise the temperature of the pile, thus increasing the rapidity of the reaction. As the temperature of the pile continues to rise combustion ensues and at this point the carbon burns to form carbon dioxide gas. When combustion occurs, the quantity of sulphur gas escaping into the air causes a disagreeable suffocating odor in the vicinity of the burning pile. In the presence of moisture an aqueous solution of sulphur dioxide is formed, which by absorption of oxygen from the air and also by combination with water forms sulphuric acid with evolution of heat thus further raising the temperature of the pile and accelerating chemical action. Thus is explained the familiar

[1]Analysis by Prof. A. J. Clark, Michigan Agricultural College.

fact of observation that burning takes place most rapidly in wet weather and is especially active immediately following a rain when the waste piles are saturated with water. The sulphuric acid unites with the bases present in the rocks to form soluble sulphates which are brought to the drying surfaces of the rock fragments by capillarity and left on evaporation as a white efflorescent coating which washes off in rainy weather to appear again in dry weather when evaporation is active. A white efflorescent coating is frequently found on drill cores of black slate which have been stored for some time in doors and also on exposures in open workings.

The black slates are closely associated in occurrence with the Vulcan formation, being frequently interbedded with it, occurring in discontinuous lenses within it, and often forming walls on which or between which ore bodies are found. It has been stated that carbonaceous matter, the essential constituent of black slate, is widely disseminated in the Vulcan formation. The "hard siliceous black slate" described in drill records and often exposed in mine workings is really highly carbonaceous iron formation. To the drill men the occurrence of black slate or "graphite" is an indication of the proximity of "ore formation." In the most generally accepted theories of the origin of the Lake Superior iron formations which have been published up to this time, the occurrence of carbonaceous matter in the iron formations and in associated carbonaceous slates has been interpreted as evidence of the presence of organic matter, mainly plants, in the waters in which deposition occurred and the organic matter is believed to have been instrumental in the formation of iron carbonate. That the presence of associated carbonaceous matter (whether of organic or inorganic origin) has some causal relation to the occurrence of iron carbonate is generally accepted by students of Lake Superior geology. Whatever the explanation may be, the characteristic close relation in occurrence of black slate and iron formation is not entirely a matter of chance association.

Associated and frequently interbedded with the Vulcan formation are slates of various kinds whose characters and relations to the Vulcan formation can be described in detail only by reference to specific occurrences. This is the author's excuse for introducing here a few type descriptions.

(2). *Chloritic, biotitic, quartz slate.*—On the Barrass explora-

tion of the Verona Mining company, in a drill hole 400 feet W. and 1,120 feet S. of the N. W. corner of the N. E. corner of Section 36, T. 43 N., R. 35 W., slaty rocks described in drill records as "granular cherty green and gray slate" are interbedded with chert and ferruginous slate. The hole, pointed east at an angle of 70°, penetrated:

0- 85	feet	overburden.
85- 92	"	chert and ferruginous slate.
92-105	"	granular green and gray slate.
105-120	"	ferruginous chert and slate.
120-131	"	granular green and gray slate.

The *"granular green and gray slate"* proves, on microscopical examination, to be a chloritic, biotitic, quartz slate, carrying a few scattered grains of iron carbonate. About 50% of the rock is quartz in small irregular grains which are embedded in chlorite and biotite, while opaque and semi-opaque blotches of material having no definite optical properties are rather abundant.

(3). *Chloritic, sericitic, quartzose and feldspathic, carbonate slates.* At the pumping station in No. 2 shaft on the fourth level of the Dober mine is a dense massive greenish colored rock, locally referred to as "green rock." Under the microscope a thin section presents a mesh of chlorite and sericite in which are embedded numerous grains of carbonate and quartz, the latter in small irregular detrital grains, and rarely a small fragment of plagioclase feldspar. Brownish, semi-opaque material having no definite optical properties is scattered in blotches through the slide.

The position of this rock with reference to the Vulcan formation is not clear. It probably underlies on the southeast the ferruginous chert and ore of the Dober mine with which it is in contact.

(4). *Sericitic-biotitic schists.*—Sericitic, biotitic schists are exposed in a series of outcrops in the N. W. ¼ of the N. E. ¼ of Section 12, T. 42 N., R. 35 W., northwest of the Youngs mine. The strike of the schistosity is N. 60° to 70° west, and dip, on the whole, highly inclined northeastward. Cleavage surfaces exhibit the silvery luster of sericite when not stained with iron oxide. Microscopic examination reveals a mass of very small flakes of sericite, biotite and chlorite in which minute grains of quartz are sparingly disseminated. Ferric oxide is rather abundant. It is mainly

secondary to pyrite as shown by its pseudomorphs after the latter.

The strike of these slates would carry them under the Vulcan formation in the Youngs mine. To the north they are overlain by black slates and the Vulcan formation shown in explorations on the Fogarty property and in outcrop on the Iron River in the S. ½ of the S. ½ of Section 1, T. 42 N., R. 35 W. In a ravine leading from the Youngs mine eastward to Iron River these schists occur in alternate bands with chert characteristic of the Vulcan formation.

(5). *Chloritic-biotitic-quartz schists.*—These rocks with variable characteristics form in large measure the footwall of the old Riverton pit. On the plats and cross sections of the Riverton mine[2] they are called "green rock." A specimen taken from an outcrop south of the Riverton pit on the road leading up Stambaugh hill presents under the microscope a completely interlocking mosiac of quartz, mainly coarsely crystalline, some individuals being greatly elongated in the plane of schistosity. Chlorite and biotite are intimately mixed and intergrown and enclose many areas of finely crystalline silica. Biotite and chlorite are also associated along fracture planes and form stringers separating the crystal individuals in the quartz mosaic. Pyrite is sparingly present, but in most cases it has oxidized to hematite. The rock is completely recrystalline and is properly termed chloritic, biotitic, quartz schist.

(6). *Hematitic, chloritic, quartz slates* at south end of Riverton pit. In mineral composition (5) is related to a massive, mottled, greenish and reddish rock, occurring on the strike of (5) in the south end of the old Riverton open pit. A specimen studied in thin section showed numerous rounded to subangular quartz grains associated with areas of very finely crystalline quartz aggregates in a matrix composed of abundant chlorite and hematite with a small quantity of biotite and an occasional minute crystal of zircon. In the greater part of the section quartz, chlorite, hematite and biotite are intermixed in confused manner, each of these minerals being in places enclosed in combinations of the other three. In many instances finely crystalline quartz, hematite, and chlorite are associated in oval areas of faint outlines resembling altered forms of greenalite granules. Hematite is in some cases arranged concentrically about rounded aggregates of finely crystalline silica and in others about single individuals of limpid quartz.

[2]Furnished through the courtesy of the Oliver Mining Co.

Similar rocks occur in a ravine at the S. W. corner of the S. W. ¼ of the N. W. ¼ of Section 36, T. 43 N., R. 35 W., apparently lying between the magnetitic-chloritic-sideritic slates of Stambaugh hill and ferruginous chert and ore shown in pits about 112 to 130 paces west. Their stratigraphic position here is apparently the same as in the former locality at the Riverton pit.

(7). *Sideritic graywacke.*—On the Hiawatha mine location, (S. W. ¼ of the S. E. ¼ of 35-43-35) in a drainage ditch following the north side of the ravine which extends in a northeasterly direction across the property, the interbedded relations of the Vulcan formation to slates and graywackes of varying characteristics are well exhibited. At a point about 300 paces south and 60 paces west of the center of the S. E. ¼ of the section massive, dense, black, fine grained graywacke is exposed, striking about N. 50° W., bedding about vertical. As the trench is followed westward, at about 120 paces the graywacke gives way to soft, dark, carbonaceous and somewhat ferruginous slate, which in turn is succeeded by siliceous black slate carrying dark cherty bands exposed in the dump of a test pit about 100 paces farther on. At the end of the trench about 120 paces S. 20° W. of the latter locality leanly ferruginous chert is interbedded with rocks having the outward appearance of graywacke and black and brown somewhat ferruginous slates. At points in the trench where the rocks are not exposed fragments which have been thrown out on the embankment indicate that gradational phases between the various types described are present.

The dense, black graywacke exposed at the east end of the pit is of especial interest because it represents a halfway stage between the Vulcan formation, which in its pure phases shows no traces of fragmental origin, to typical graywacke, a wholly fragmental rock.

Microscopic examination shows that the rock is composed of the minerals quartz, chlorite, carbonate, biotite, plagioclase, orthoclase, sericite, pyrite, and opaque to semi-opaque material not differentiated, probably carbonaceous.

Quartz occurs in (1) angular, detrital grains, (2) as recrystallized silica enclosing both chlorite and carbonate, (3) and in rounded to oblong areas of finely crystalline aggregates associated with chlorite and hematite.

Hematite is especially associated with chlorite, penetrating it in needle-like crystals and frequently enclosed in it.

Carbonate is abundant in granules and rhombic sections scattered through the slide. Some of the carbonate rhombs show zonal arrangement of coloring, green on the interior, becoming yellowish and then brownish as the periphery is approached, a phenomenon of incipient alteration rather than of zonal growth of the crystal, although in slides examined the common alteration of carbonate to hematite was not noticed.

Biotite, commonly associated with meshes of chlorite and also in fracture planes cutting quartz grains is plentiful, and sericite is very sparingly present in minute flakes.

Detrital grains of orthoclase and plagioclase feldspar are scattered through the rock in abundance. A few show incipient cloudy alteration, but most of them are fresh and clear.

Opaque, black and brown material, probably carbonaceous, is scattered widely through the rock, but seems to be especially associated with the carbonate.

From the description given in the preceding paragraphs it is evident that this rock partakes of the nature both of an ordinary graywacke and of the cherty iron carbonate of the Vulcan formation and must be considered as one of the many gradational phases between the Vulcan formation and associated clastic rocks. Mr. H. L. Botsford reports that similar rocks are found in association with ferruginous chert in the Chicagon mine.

(8). *Sideritic-magnetitic graywacke.*—Southeast of the Chicagon mine in the S. W. ¼ of the N. E. ¼ of Section 36, T. 42 N., R. 34 W., are outcrops of dark magnetic sideritic graywacke, strike N. 40° W., dip 60° southwest. In texture and composition this rock is analogous to the sideritic graywacke on the Hiawatha mine location, with the exceptions that magnetite is abundant and epidote, not observed in the Hiawatha rocks, is sparingly present. Associated with them are chloritic-sideritic-magnetitic slates, exactly similar to those on Stambaugh hill. (See pp. 56-59.)

Other slates differing in unimportant particulars from some one of the eight varieties described above might be added to the list but little would be gained in so doing. Enough has been said to establish the fact, already emphasized, that the various phases of the Michigamme slates associated with the Vulcan formation are in endless variety of gradational relations to the latter and to each other. Such relations are due to changing conditions of deposition both in time and from place to place on the bed of the sea in which the Michigamme

series accumulated, a discussion of which is given in a later chapter.

MICHIGAMME SLATES IN THE NORTHERN PART OF THE DISTRICT. (PAINT SLATES.)

The Paint slates are exposed in the valley of the Paint River, and in the valleys of tributary creeks. They are mainly quartzose and feldspathic sedimentary rocks exhibiting the general characters of graywacke and arkose. They vary in texture from conglomeratic to fine grained and in structure from massive thick bedded rocks to micaceous schists. Bedding is well marked on many exposures in the northeastern part of the district but westward it is generally obscured or obliterated by recrystallization and development of micaceous minerals resulting in schistose structures. From the structural standpoint there is no evidence to explain why the rocks should in this direction exhibit a higher degree of metamorphism, because the development of schistosity seems not to be accompanied by more intense folding. The explanation seems to lie in original finer textures, which would enable the rocks to more readily recrystalize under the same conditions of metamorphism. The structure of the Paint slates has already been described.

The mineral composition of six typical graywackes of the Paint slate formation is shown in the table below.

MINERAL COMPOSITION OF SIX THIN SECTIONS OF TYPICAL GRAYWACKES OF THE PAINT SLATE FORMATION.

No. *	Quartz.	Plagio-clase.	Ortho-clase.	Chlorite.	Sericite.	Biotite.	Epidote.	Zoisite.	Carbonate.	Sphene.	Zircon.	Ferrite.
1....	x	x	x	x	x	x	x	......	......	......	......	x
2....	x	x	x	x	x	x	x	......	......	......	......	......
3....	x	x	x	x	x	x	x	......	x	......	......	......
4....	x	x	x	x	x	x	x	x	......	......	......	......
5....	x	x	x	x	x	x	......	......	x	x	......	......
6....	x	x	x	x	x	x	......	......	x	x	x	......

*1. From outcrop 750 paces E. and 175 paces N. of the S. E. corner of section 24, T. 44, N., R. 34, W.
2. From outcrop 500 paces E. and 300 paces N. of the S. W. corner of section 24, T. 44, N., R. 34, W.
3. From outcrop near location of 2.
4. From outcrop 850 paces S. of N. E. corner of section 18, T. 44, N., R. 35, W.
5. From outcrop near center of section 29, T. 44, N., R. 35, W.
6. From outcrop 250 paces E. of center of section 19, T. 44, N., R. 34, W.

These specimens from widely separated outcrops extending from the eastern to the western side of the area have markedly similar mineral compositions. Quartz, plagioclase, orthoclase, chlorite, sericite, biotite, and epidote are the characteristic minerals, while zoisite, carbonate, sphene, zircon, and ferrite are accessory. Quartz is more abundant than feldspar and, of the latter mineral, plagioclase predominates over orthoclase. Chlorite, sericite, and biotite are abundant in all specimens, the two latter increasing in importance in the more schistose varieties. These minerals, being of finer grain, form a ground mass in which the clastic particles of quartz and feldspar are embedded. They also occur together with carbonate and quartz in areas of altered feldspar, usually plagioclase. Epidote is plentiful in (1), (2), (3), and (4). It occurs in scattered grains and clusters of grains, usually altered to chlorite on the periphery in a few cases the alteration being complete. When zoisite occurs it is in zonal intergrowth with epidote but this mineral is rare.

The Paint slates carry lenses of Vulcan iron formation with associated carbonaceous slates, as at Morrison creek and Atkinson. They are also interbedded at various horizons with greenstone agglomerates and tuffs.

BASIC INTRUSIVES AND EXTRUSIVES IN THE UPPER HURONIAN GROUP.

Igneous rocks of basaltic type are abundant in the upper Huronian group. The distribution of those now known is indicated on the accompanying map of the Iron River district (Plate 1). There is much difficulty in determining the general distribution of these rocks because the relations to the slates are so intricate that it is never safe to conclude that adjacent exposures are, or are not, separated by slate.

The rocks are principally of extrusive type and have surface textures, especially the ellipsoidal and agglomeratic textures, so characteristic of the Hemlock formation and of the volcanics associated with the upper Huronian of the Crystal Falls district. Some of these extrusives are distinctly contemporaneous with the slates. Southwest of Atkinson agglomeratic and tuffaceous phases of the greenstone are interbedded with slate and iron formation of the upper Huronian group. (Fig. 15.) In the southern part of the district, Section 23, T. 42 N., R. 34 W., ellipsoidal and tuffaceous

greenstone occurs north of the Upper Huronian slates in a northward dipping series. From the lack of contact metamorphism and the abundance of tuffaceous phases and effusives they were probably nearly all deposited contemporaneously with the sediments. It follows that the deposition was probably subaqueous. Definite evidence of relations is lacking for many greenstones, especially those not adjacent to slates or some of those which have been developed by mining operations and explorations.

Greenstones in the southern part of the district.—A belt of isolated outcrops of volcanic greenstone, following the trend of the Saunders formation south of it, extends across the southern part of the district. These rocks seem to lie in a stratigraphic horizon between the main part of the Michigamme series above and the Saunders formation below. They occupy the same stratigraphic position with reference to overlying slates and underlying dolomite as do the Hemlock greenstones of the northern Crystal Falls district. However, it is well to avoid the use of the term Hemlock here since it has been used by Clements with a stratigraphic significance, i. e., in designation of volcanic greenstones of *Lower Huronian* age occurring between the Michigamme (Hanbury) series above, and the Randville dolomite below. It is probable, as shown above, (p. 50) that some of the greenstones mapped by Clements as Hemlock are of Upper Huronian age and since in the Iron River district volcanic greenstones occur at various horizons in the Michigamme series, as do the Clarksburg volcanics of the Marquette district, the term Clarksburg is more preferable than Hemlock. It is important to bear in mind that the essential facts of occurrence of the Huronian volcanics are the same in the Crystal Falls, Iron River, and Gogebic districts and probably also in the Menominee district. In the Crystal Falls district volcanic activity began after the close of Randville time, continued through Middle Huronian time[3] into Michigamme time. In the Gogebic district the volcanics are contemporaneous with the Upper Huronian of the eastern end of the district. In the Menominee district contemporaneous volcanics are not *certainly* known, but it is possible if not probable, that the western green schists well exposed at the lower and the upper Twin Falls on the Menominee

[3]A Middle Huronian series has not yet been recognized in the Crystal Falls district, but if present it probably lies below the Michigamme (Hanbury) series and above the Randville formation. This horizon seems to be occupied, at least in part, by the Hemlock volcanics.

River and east and west of this locality, referred by Bayley to the Keewatin (Quinnesec schists), are of Upper Huronian age. There is no evidence favoring the one hypothesis more strongly than the other, but westward in the Florence district of Wisconsin, on the strike of these rocks, are similar greenstones which are certainly interbedded with the Michigamme (Upper Huronian) series. In the Iron River district volcanic activity was recurrent at intervals and was possibly continuous from Saunders time (Lower Huronian) well on into Michigamme time (Upper Huronian).[4]

It is, therefore, clear that the Iron River district is part of a region in which volcanism was more or less active during Upper Huronian time. It is improbable that volcanic activity began simultaneously or closed simultaneously everywhere in this wide area. Periods of activity in one district may correspond to periods of quiescence in another and in a single small area, as in the Iron River district, there were alternate periods of activity and quiescence. In the light of these facts the task of closely correlating the volcanics of one district with those of another is obviously one of extreme difficulty if not impossible.

PARTICULAR OCCURRENCES OF GREENSTONES IN THE SOUTHERN PART OF THE DISTRICT.

Section 24, T. 42 N., R. 34 W.: Ellipsoidal and tuffaceous greenstone occurs north of Brule river, extending from the west line three-fourths of a mile slightly northwest through the center of the section. A few outcrops occur on the south side of Brule river and greenstone also occurs in a shaft at the old Jumbo exploration. (See fig. 3 and pp. 65-66.) In the outcrops on the north side of the river, principally north of the C. & N. W. Ry., the ellipsoidal structure is well developed. The ellipsoids are, on most surfaces, distinct and vary in size up to a foot in longest diameter. On weathered surfaces the ellipsoids are a light green in contrast to the yellowish color of the matrix surrounding them. Except in a single outcrop the rock is very schistose (strike slightly N. W., dip vertical) and exceedingly fine grained. The only minerals identified without the use of a microscope are chlorite and iron pyrite. A particularly noticeable character is the large amount

[4]Since this paragraph was written Mr. W. O. Hotchkiss, State Geologist of Wisconsin, has shown by work in the Florence district that the Quinnesec schists of the Menominee district are probably not older than Upper Huronian. (Personal communication.)

of dolomite developed irregularly throughout the rock and especially in cracks and cleavage planes.

On the south bank of Brule river the greenstone is massive on the whole and fine grained showing faint traces of ellipsoidal structure in only one place. In other places it looks like a schistose amygdaloid especially at the south end of the exposures. At the north end it is more massive though it is spotted. Where highly weathered and decomposed the rock has a reddish color and in one place (285 paces S. and 400 paces W. of the center of the section) a tunnel has been driven some 15 feet into the rock, evidently in search of iron ore. The exposure, which is some 250 paces long, is separated by a thin bed of slate striking E.-W. and dipping 70°-90° S. The contact with the greenstone is rather sharply defined. The contact planes dip south, about 85° on the north side and 45° on the south side. At the water's edge the slate bed is about six feet thick narrowing upward to not more than four feet. (Plate 7.) The slate is dark, exceedingly hard and brittle and cut by innumerable fine seams of quartz and pyrite. Under the microscope it appears to be an exceedingly fine grained chloritic quartz slate. About 85% of the rock is chlorite. Sericite is sparingly present in minute flakes and occasionally a spangle of biotite. Pyrite is abundant but much of it has oxidized to hematite. Secondary quartz occurs in stringers and veinlets filling minute fractures, and in original disseminated fine grains.

The greenstones seem to be interbedded on the south with the slates and Vulcan formation of the Jumbo belt. The north boundary follows the magnetic line which runs just north of the outcrops slightly west of north into section 21 (see map, Plate 1) where it dies out.

Section 21, T. 42 N., R. 34 W.—About two miles slightly N. W. of the exposures in section 23 is an isolated exposure of greenstone agglomerate. The outcrop occurs about 400 paces S. and 275 paces E. of the N. W. corner of Section 21 at the west base of a prominent hill. The rock forms a jagged mass of angular fragments of light colored greenstone in an amygdaloidal schistose matrix. It is highly decomposed, secondary dolomite being more abundantly developed here than in the ellipsoidal greenstones in section 23. (Plate 8.) The magnetic line, which crosses the east line of the

section at about 650 paces south of the N. E. corner, if extended would pass just north of this outcrop.

Section 18, T. 42 N., R. 34 W. The Wild Cat Shaft.—Westward, the next occurrence of greenstone is at the Wild Cat Shaft about 1,570 feet south and 50 feet east of the center of the section. The shaft is filled with water. The rocks which have been thrown out on the dump include highly decomposed greenstone and cherty and chloritic carbonate rocks of the Vulcan formation. The disposition of the rocks in the dump indicates that the greenstone was encountered beneath the slates but further than this the structural relations between the two formations are not known. The greenstone is of medium grain and may be either extrusive or intrusive.

The slates are gray, green, and yellowish in color, well banded and laminated, and are cut by innumerable fine intersecting fractures. In composition they vary from cherty iron carbonate, carrying some chlorite, to highly chloritic, biotitic and hematitic varieties. The content of siderite never reaches above 35% of the volume of the rock. There are a few pieces of hard siliceous hematite on the dump showing that locally alteration to iron ore has been accomplished.

On the basis of relations shown at the Wildcat shaft the boundary between the slate-iron formation series on the north and the greenstone-slate series on the south has been extended westward from the N. W. 1/4 of the N. W. 1/4 of Section 21 through a point a short distance south of the shaft.

Section 13, T. 42 N., R. 35 W.—In a low ridge extending east from the road running diagonally across the N. E. 1/4 of the N. W. 1/4 of the section to within 80 paces of Iron River are numerous exposures of greenstone. The ridge is flanked on the north by low ground which is strewn at the base of the ridge with angular blocks of slate, some of them of large size. The slate is nowhere exposed in place and its relations to the adjacent greenstone cannot be observed. However, it is certain that the slate is in contact with the greenstone near the base of the ridge, because the slate fragments show by their large size, angularity and abundance that they have not been carried far by either ice or water.

At the west end of the exposures the greenstone is dark colored, massive, dense and fine grained, similar to that in the Jumbo shaft

except that it is less decomposed. Toward the east the rock becomes lighter in color and the surfaces exhibit the peculiar pock marked appearance of variolitic greenstone. The spherules vary up to a half inch in diameter and are evidently more resistant than the matrix surrounding them as they project above it in mammillary protuberances. The spherules differ in color from the matrix. They are light gray while the matrix is light green. (Plate 9 B.)

An occurrence of variolitic basalt in the Upper Huronian volcanics has been described by Clements[5] from T. 44 N., R. 33 W., Section 4, 375 paces south and 900 paces west of the S. E. corner. This occurrence is "in close proximity to the remnant of a basalt stream which shows well marked flowage structure," but "the relations of the two rocks are not determinable from the exposures." The Iron River occurrence is a short distance (150 paces) southeast of a large exposure showing well developed agglomeratic structure. The fragments are well rounded, vary up to a foot in diameter and are embedded in a matrix of material differing from them only in being finer grained. (Plate 9 A.) The rounded character of the fragments makes the term *eruptive pseudo-conglomerate* applicable to this rock, rather than *eruptive breccia.* This structure has been described by Clements[6] as it occurs in the Hemlock volcanics of the Crystal Falls district. The exact method of formation of the eruptive pseudo-conglomerates and breccias is not known but the brecciated and pseudo-conglomeratic structures are especially characteristic of surface lavas. In discussing the origin of these structures, Clements says: "In one case in which both fragments and matrix are amygdaloidal it appears probable that the occurrence represents a true flow breccia in which the broken surface of a lava flow had been recemented by a later flow of the same kind of rock, or that it represents a very possible case in which lava welled up through and flowed over portions of its own crust, cementing the fragments. In one instance, in which both the fragments and matrix were microscopically non-amygdaloidal, it is probable that they were formed under considerable pressure, and that this was a case in which lava was forced up through a previously consolidated mass of rock of like char-

[5]Clements, J. Morgan. U. S. Geological Survey, Monograph 36, pp. 108-111.
[6]Ibid. p. 136.

acter, and in its passage carried with it various fragments, forming an eruptive *'reibungs breccia'* or *friction breccia."*

Whatever the exact manner of formation of the pseudo-conglomeratic and variolitic structures may have been, their occurrence is pretty good evidence of the extrusive character of the greenstones in which they are found.

The slates at the north base of the greenstone ridge are especially interesting in the light of the extrusive origin of the greenstone. These rocks are really unique and are dissimilar to all others thus far found in this district. Weathered surfaces are gray, green, purple and yellowish and show very distinct banding and fine lamination. The banding is especially noticeable on some specimens where it is accentuated by the more resistant character of some of the bands which causes them to stand out above the softer ones producing a ribbed appearance. In some of the specimens the prominent bands seem to be of feldspathic composition. They are grayish white to pink, contrasting strongly with the separating green bands of chloritic composition. Other bands are marked by large numbers of whitish gray grains of decomposed material which vary in diameter up to 1-16 of an inch. There are also fine dense laminæ of dark cherty material, seldom as much as 1-8 inch in diameter. Occasionally the rock presents a very finely pitted surface produced by the weathering out of some mineral, producing minute cavities in the weathered surface. The shapes of the cavities are usually irregular but some appear to be molds of either cubes or rhomboids near cubes in form. The pitted laminæ are of chloritic composition.

Under the microscope these rocks exhibit an exceedingly fine mesh of intergrowths of chlorite and sericite, the former being greatly preponderant. The chlorite is in many places discolored by hematitic alteration. Scattered through the rock are areas of brownish semi-opaque material which does not extinguish on rotation between crossed nicols.

Narrow bands of siliceous material, made mainly of extremely irregular quartz individuals with interlocking texture, cut the thin sections. Rarely there are nicely rounded quartz grains in these bands. The quartz is usually dirty with inclusions in which sericite has been identified. There are also many areas of quartz, sericite, and chlorite having outlines suggestive of feldspar of which they may be altered products.

The appearance of these rocks, microscopically and macroscopically, and their close field association with basic extrusive greenstone strongly suggests a genetic relation to the latter. If the basic lavas represented by the greenstones had welled upward and poured out on the bottom of a water body in which sedimentation was taking place it is easy to imagine that detritus from the lavas would enter into the composition of adjacent sediments. Such has *possibly,* and I have little hesitation in saying *probably,* taken place here. The microscopic appearance of these slaty rocks suggests at once, especially if combined with examination in the field, "greenstone material." Other instances are known where basic eruptive breccias actually grade along the strike into sediments which seem to differ from them slightly, if any, in composition, and gradational relations are such that it is impossible to separate them by any line that might be drawn.

The relations between slate and greenstone are not more satisfactorily indicated here than at the Wildcat shaft (p. 105) but on the supposition that the slates are younger than the greenstone, and since explorations in adjacent territory to the north and northeast have not indicated the presence of greenstone, the north boundary of the latter (which carries interbedded slate) has been extended northwestward from the Wildcat shaft, passing just north of the exposures.

T. 42 N., R. 34 W., Section 29.—Near the southeast corner of the N. E. ¼ of the N. W. ¼ of the section, extending southwestward about 250 paces are numerous exposures of greenstone. They are of especial interest because they exhibit well developed flowage structures not observed elsewhere in the district. A notable feature of the rock is its porphyritic character irregularly developed in small local areas and especially in those showing flowage lines. The porphyritic mineral is plagioclase feldspar. This feature is exceptionally well shown on weathered surfaces where the grayish white color of the porphyritic feldspar is in contact with the green ground mass of the rock. Most of the feldspars are twinned after the Calsbad law. The ellipsoidal structure is also present in some places but is only weakly developed. A few areas showing distinct ellipsoids are surrounded by others in which are indistinct ellipsoidal outlines and these grade away into the dense fine grained green rock showing neither ellipsoidal nor flow structure.

T. 42 N., R. 34 W., Section 19.—On the east side of Brule river in the vicinity of the south one-quarter post of the section, greenstone occurs in a number of exposures. It is of the common, dense, fine-grained, pyritic variety grading into hard, flinty and slaty phases of purplish gray color which bear resemblance to the slates interbedded with greenstone on Brule river (described on p. 104).

T. 42 N., R. 35 W., Section 24.—Interesting exposures occur in the S. E. ¼ of the N. E. ¼ of the section just north of the E.-W. quarter line, forming an overhanging ledge in which several varieties of rocks occur. Greenstone of the dense, fine-grained, green variety is associated with hard, brittle, purplish rocks similar to those in the locality on Brule river just described. Gradation from the green to the purplish color may be observed in hand specimen. With the dense green and purplish varieties are others which show distinct lamination, the origin of which is not clear. Some phases show narrow siliceous bands alternating with finely laminated yellowish-green bands, strongly suggestive of sedimentary origin, while other phases show very irregular interbanding of pink and purple colors, and in one case this phase was found in contact with the dense fine-grained green variety, the contact plane being sharp and showing truncation of the bands or laminæ. That the banded and laminated structures are not secondary but original seems reasonably clear. They resemble more closely stratification produced by deposition of sediments in air or water rather than the fluxion structure of lava, schistosity, or banding produced by metamorphism but their exact manner of formation has not been determined.

North of this greenstone exposure, along the N.-S. line between the N. E. ¼ of the N. E. ¼ and the N. W. ¼ of the N. E. ¼, holes drilled by the Pewabic Mining Company are reported to have penetrated slate with the northernmost hole in quartzite and dolomite. Samples from the drill holes were not seen.

T. 42 N., R. 35 W., Sections 14 and 16.—In section 16 are a number of greenstone exposures beginning about 200 paces north of the S. ¼ corner and extending north about 200 paces, beyond which at about 50 paces is a test pit showing greenstone on the dump. This greenstone is dark, fine grained and magnetic. Dip needle readings are as high as 25° on the southernmost outcrop, decrease northward and become normal or 0° at about 150 paces north of

the pit. Other greenstone exposures occur about 100 paces slightly S. E. of the W. ¼ post of Section 16 and also at 650 paces north and 285 paces west of the S. E. corner of Section 12, T. 42 N., R. 36 W.

Summary.—The greenstones of the southern part of the district are of basaltic composition. They exhibit the general characteristics of extrusive lavas and tuffs in their general fineness of grain, ellipsoidal, agglomeratic, and fluxion structures. They are interbedded, at least to some extent, with sedimentary rocks, from which the inference may be drawn that they were at least in part contemporaneously and subaqueously deposited with the associated sediments.

GREENSTONE IN THE NORTHERN PART OF THE DISTRICT.

The northern greenstones do not differ in any essential respects from those in the southern part of the district and for that reason descriptions of particular occurrences will be omitted. So far as known the outcrops appear on the map. (Plate I.)

Field relations indicate that the northern greenstones, mainly extrusives, occur at various stratigraphic horizons in the Paint slate. The Atkinson section has already been described (p. 90-93 and fig. 15). Another instructive occurrence is in the N. W. ¼ of Section 29, T. 44 N., R. 35 W. Greenstone occurs in a ridge extending from a point on the C. & N. W. R. R. track about 750 paces south of the N. W. corner, northwestward for about a half mile. Passing along the crest of the ridge the ordinary phases of coarse greenstone agglomerate and tuff are found. These are replaced by rocks of finer grain and marked schistosity, which in turn are replaced by mica schists showing almost perfect cleavage. The latter are a very common phase of the Paint slate formation. Evidently the greenstone is replaced along the strike by slate through a series of gradational phases.

It is exceedingly difficult to distinguish in the field between some phases of the Paint slate and schistose greenstone just as it is sometimes difficult to find the line of contact between granite and recomposed granite (arkose) when these are associated. Both are of the same, or near the same, composition, and texture alone is often the deciding factor in distinguishing between them. But if the original textures in both rocks have been obliterated by the

formation of a common schistose structure the task of distinguishing between them, in some instances, becomes almost impossible.

If the greenstones originated under subaqueous conditions in the water body in which the Paint slates were being deposited it is certain that quantities of detritus from the greenstone would intermingle with adjacent sediments, and such would certainly be true if the greenstones were pyroclastic, as many of them are. It is probable that volcanism in Michigamme time was active both in sea and on land as it is now in certain volcanic regions of the globe.

It has been said that the northern greenstones, like the southern, are mainly extrusive. Medium grained phases occur in the S. E. 1/4 of Section 17, and near the W. 1/4 corner of Section 19, T. 43 N., R. 35 W., and in the N. W. 1/4 of Section 1, T. 43 N., R. 34 W. The coarser grained phases may be intrusive but this cannot be proven because of total absence of exposures showing relations with surrounding rocks.

It may be well to recall here that the greenstone exposures in the eastern part of the district just south of the Paint river seem to be continuous with others in an area in the Crystal Falls district mapped by Clements[7] as Hemlock volcanics (Lower Huronian). The westward extension of this belt is indicated in the outcrops in Section 25, T. 44 N., R. 35 W., and in Sections 12, 16, 17, 19, 6, and 7, T. 43 N., R. 35 W. These outcrops are separated by drift-covered areas and it is of course impossible to ascertain whether they are connected to form a practically continuous mass or whether they are isolated occurrences in the Michigamme series. If the latter is the case they cannot be proven Hemlock in age while if the former is true the age of the mass can be shown to be more probably Michigamme. If these rocks are Lower Huronian they must underlie the Michigamme series, in which case their exposure here is doubtless due to erosion of an anticline. Such was the opinion of Clements and the eastward continuation of this mass almost to Crystal Falls was mapped as an anticline. If such anticline exists and is continuous across the Iron River district, the sedimentary section on opposite limbs of the anticline should be the same. Though information is meagre this seems not to be the case, for the Paint slates on the north, as a whole, do not

[7]Monograph 36, U. S. G. S. See geological map accompanying.

closely resemble the Michigamme of the producing part of the district. Yet in view of the rapidly varying conditions of sedimentation from place to place in the Michigamme sea this argument loses some of its force. Equivalent formations in closely adjacent areas are not necessarily lithologically the same or even similar. However, north of the belt in question interbedded Michigamme slate and greenstone occurs, notably near Atkinson, and this, with the general structure of the district and absence of contrary evidence, leads me to believe that such are the relations between the greenstone and Michigamme slate in the belt in question.

RELATIONS OF THE UPPER HURONIAN GROUP TO THE SAUNDERS (LOWER HURONIAN) FORMATION.

No direct evidence of the relations of the Upper Huronian group to the underlying Saunders formation is yet available. Certain slates conformable with the Saunders formation in Sheridan hill *may* be Upper Huronian slates and *may* therefore indicate the conformable relations between the Upper Huronian slates and the Saunders formation. The fact that the rocks of the Saunders type form a continuous belt between the Upper Huronian slates and the Archean shore to the south is evidence of nearly conformable relations. In the Florence district there are quartzites, presumably forming the conformable base of the Upper Huronian group, and in the Crystal Falls, Menominee, Felch and Calumet districts succession from underlying quartzite and dolomite to the Upper Huronian show familiar relations.

By reference to the map (Plate I) it will be seen that the north boundary of the Saunders formation would have to form a curve, convex southward with west end in the southwest ¼ of Section 19 and the east end at the exposure at Saunders dam, T. 42 N., R. 34 W., in order to exclude the greenstones in Section 29 and near the south ¼ corner of Section 19. According to the notes of Professor W. S. Bayley (1901), cherty dolomite was encountered in a well 600 paces north and 50 feet west of the S. W. corner of Section 24, T. 42 N., R. 35 W., by James Burgess, a driller employed by the Pewabic Mining company. If this information is authentic it furnishes additional evidence that the greenstones in Sections 19 and 29, T. 42 N., R. 34 W., are interbedded with the Saunders formation.

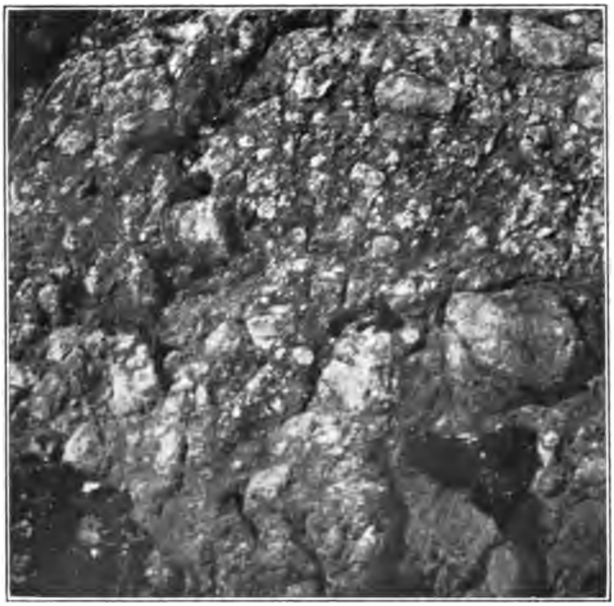
(A) VULCAN FORMATION IN THE SOUTH END OF RIVERTON PIT. THE BANDING OF THE FERRUGINOUS CHERT IS WELL SHOWN.

(B) VULCAN FORMATION IN SOUTH END OF ISABELLA PIT.

SLATE INTERBEDDED WITH VOLCANIC GREENSTONE ON BRULE RIVER, ABOUT TWO MILES EAST OF SAUNDERS.

(A) WEATHERED EXPOSURE OF VOLCANIC GREENSTONE BRECCIA IN SECTION 21, T. 42 N., R. 34 W., NEAR SAUNDERS. NOTE THE GREAT ABUNDANCE OF CALCITE AND DOLOMITE SHOWN IN WHITE.

(B) A NEAR VIEW OF A PORTION OF THE EXPOSURE SHOWN IN (A).



(A) ERUPTIVE GREENSTONE PSEUDO-CONGLOMERATE IN SECTION 13, T. 42 N., R. 35 W.

(B) WEATHERED SURFACE OF GREENSTONE FLOW. SAME LOCALITY AS (A).

ORDOVICIAN. SHERIDAN FORMATION.

Remnants of a flat lying Palaeozoic member occur in the southern part of the district on Sheridan hill and vicinity and southwestward in the S. W. 1/4 of Section 27, T. 42 N., R. 35 W. and in the northern part of Section 24, T. 44 N., R. 35 W.

The base of the member on Sheridan hill is a conglomerate made up almost entirely of material from the underlying Saunders formation. Angular fragments of chert up to a couple of inches in diameter lie in a matrix of the same composition, on the whole, but finer grained. The rock is cemented mainly with iron oxide and calcium carbonate. The thickness of the conglomerate is unknown but is not great. The conglomerate has not been found in natural exposure but occurs abundantly on the dumps of pits which have been sunk through it into the Saunders formation.

The conglomerate is probably basal to a coarse, quartz sandstone of buff or red color, and generally very friable texture. The cement is mainly iron oxide. Under a slight tap of the hammer the rock falls apart into its constituent sand grains. The thickness of this member is not known but it probably varies up to perhaps 35 or 40 feet. Like the conglomerate, the sandstone is known only in pits. It may be seen to best advantage about 550 paces west and a few paces south of the N. E. corner of Section 20, T. 42 N., R. 35 W. in the dump of a large pit. Some of the layers here carry abundant small chert fragments derived from the Saunders formation which is exposed in this vicinity.

In the S. E. corner of Section 24, T. 44 N., R. 35 W. a film of red sandstone is found mantling black slate. Here the rock carries considerable iron oxide, probably derived from the Vulcan member occurring about a quarter of a mile north of it.

The conglomerate and sandstone of these areas have the lithological characters of the lowermost Cambrian beds in the Menominee district and were formerly correlated as Cambrian. Fortunately, recent fossil discoveries in flaggy limestone beds in the S. E. 1/4 of the S. W. 1/4 of Section 27, T. 42 N., 35 W., have fixed within narrow limits the age of these formations. In this area there is one natural exposure on the east side of the Brule river and several pits all showing non-magnesian, dove or buff colored, flaggy limestone of the same general characters. The rock seems to be flat lying, although the beds in the outcrop on the Brule river, where

observations were made and where most of the fossils were found, have been disturbed by slump following undercutting by the river. From the position of this outcrop in reference to an exposure of the Saunders formation on the west side of the river about 500 paces south, it seems that these rocks are not far above the eroded surface of the Saunders formation. It is not known that they are underlain by the conglomerates and sandstone of Sheridan hill. The beds are practically undisturbed in both areas, but the lowermost known occurrence of the conglomerate on Sheridan hill is about 150 feet higher and the uppermost known beds of sandstone are about 300 feet higher than the limestone outcrops on the Brule river in section 27. It seems from this that the conglomerate and sandstone on Sheridan hill is stratigraphically higher than the limestone of section 27. Doubtless the conglomerate originally formed a more or less continuous mantle at the base of the Palaeozoic member, but owing to the rugged character of the pre-Ordovician surface over which the sea advanced there was probably a considerable time interval between the submergence of the lower areas and the tops of the hills. Consequently the relative age of the basal member formed at any given point is a function of its altitude at that place. The occurrence of sandstone on Sheridan hill at an altitude of about 1,760 feet makes it certain that the entire district was almost, if not entirely, covered by a Palaeozoic sea.

The lowest exposure of the Palaeozoic beds is the limestone member on Section 27, T. 42 N., R. 35 W. This member is correlated by Mr. E. O. Ulrich on paleontologic grounds with the Lowville of New York and the Plattville limestone of Wisconsin, i. e., Middle Ordovician. The following is Mr. Ulrich's report to Dr. T. W. Stanton:

"I beg leave to report as follows on the fossils collected in the Iron River district, Michigan, by R. C. Allen, and forwarded to the Survey for examination and report by Dr. C. K. Leith, November 18, 1909.

"This discovery of fossils in Northern Michigan is of great interest, since it adds an important link in proving the former connection of the early Mohawkian limestone of Minnesota and Western Ontario across northern Wisconsin. In discussing the Lowville formation in my paper on revision of Palaeozoic systems, I state my conviction that this and perhaps other Mohawkian

formations must have originally extended from New York through Ontario, northern Michigan and northern Wisconsin to Minnesota and Iowa. This direct westerly connection was indicated by the great similarity in fauna and lithology noted in comparing the Lowville limestone in New York and the more typical part of the Plattville limestone in Minnesota, Iowa, southern Wisconsin, and northwestern Illinois. I objected to communication via southeastern Wisconsin because there the beds supposed to correspond in age to the Lowville are dolomites instead of pure limestone, with no indication of transition in lithic characters northward. Hitherto the northern connection could not be established farther west from New York than Escanaba, Michigan. This Iron River occurrence, which is of the same fine-grained, non-magnesian, dove limestone everywhere characterizing the Lowville, and lies well up on the old 'Wisconsin Peninsula,' therefore may justly be regarded as tending to establish a view hitherto based only on inference.

"The following twenty species are more or less confidently identified. All are older than the Trenton limestone and younger than the latest (Pamelia limestones) Stones River.

Fossils from Iron River, Michigan.

? *Corematocladus densus.*
Tetradium cellulosum (1 fragment of tube of only).
Rhinidictya cf. *nicholsoni* and *mutabilis-minor,* (fragment).
R. cf. *major,* (fragment).
Escharopora angularis.
? *Homotrypa arbuscula.*
Rafinesquina minnesotensis.
Strophomena incurvata (Lowville var.).
Zygospira recurvirostris (Lowville var.).
Ctenodonta sp. undet. (near *C. levata*).
Leperditia fabulites.
Leperditella tumida.
L. germana.
Bythocypris granti var.
Eurychilinia reticulata.
E. subradiata.
E. n. sp.
Isotelus cf. *ovatus.*
Pterygometopus sp. undet. (*pygidium*).

"The fossils of the above list indicate an horizon at the extreme top of the Plattville limestone in the Lead district. Compared with the New York section the age of the bed corresponds to the uppermost beds of the Lowville as described by Cushing, or to the cherty bed at the base of the Black River limestone as defined by the same author."

CHAPTER V.

CONDITIONS OF DEPOSITION OF THE MICHIGAMME SERIES.

The foregoing study of the rocks of the Michigamme series throws considerable light on the physiographic and climatic conditions of their deposition. That the sediments were laid down in water of varying shallow depths under unstable and fluctuating conditions of supply of materials is evidenced by the variability in texture and composition of individual strata, their discontinuity, cross bedding, ripple marks, frequent repetition at different horizons of rocks of identical character, and the presence of intraformational conglomerates. In the earlier studied iron ranges, viz. the Animikee, Vermilion, Mesabi, Penokee-Gogebic, Marquette and Menominee, the Upper Huronian succession is in general from the base upward, conglomerate and quartzite, iron formation, slate, representing a uniform progression of a cycle of changes in conditions of sedimentation which gave rise to a type succession for the series in these districts. In the Iron River district and also in the Florence-Crystal Falls district this order of succession breaks down completely and in place of it there is presented a series of dovetailed lenses of various dimensions of slates, graywackes, arkoses, and iron formation, usually separated by indefinite gradational zones but often showing abrupt transitions. Conditions of sedimentation were therefore not uniform in time or place. Considering the series as a whole the sediments are poorly sorted; apparently the detritus was contributed to the water faster than wave and current action could sort it. If the materials had been gained at the expense of bordering shore rocks through wave erosion they would have been more perfectly sorted. It is likely that the main source of the detritus was inland from whence it was conveyed to the sea by streams and built into a delta. Under this hypothesis the rapid variations in grain, discontinuity of beds, etc., are the result of fluctuations in transporting power of the streams combined with progressive aggradation of the bed of the sea. In times

of high water the sediments would be abundant and much coarse material would be brought down while in times of low water the sediments would be less abundant and finer grained. The effects on sedimentation of seasonal and periodic variations in rainfall would be accentuated in proportion as the relief of the land was high and rugged. As the sea bottom was aggraded by sedimentation at the river mouths the shallows advanced seaward instead of landward as happens when the sea encroaches on the land. The shore line was probably west and north of the area and this may explain the comparative coarseness of grain in the stratigraphically higher strata in the northern part of the district.

THE ROCKS FROM WHICH THE UPPER HURONIAN SERIES WERE DERIVED.

The Upper Huronian series were derived from the Archean complex of basic and acid rocks, mainly igneous, the rocks of the Lower (and Middle) Huronian series which on adjacent shores were quartzite, dolomite, some slate, igneous rocks of which probably the greater part were basic igneous extrusives, and contemporaneous basic igneous volcanics. These rocks were broken up on the land by decay and disintegration and transported to the sea by streams. The more resistant minerals such as quartz and feldspar reached the sea largely in the form of sand in less finely comminuted condition that the less resistant ferro-magnesian minerals and soluble silicates, the weathered residuum of which made mud. The former are abundant in the graywacke and arkose while the latter forms a main constituent of the slates. Iron, the alkalies, and the alkaline earths were partially dissolved and carried to the sea in soluble form. Sodium and potassium remained in solution in the sea water while the iron, calcium, and magnesium were precipitated mainly in the form of carbonate. Iron carbonate is the important original iron bearing mineral in the iron formation rocks and is also widely distributed with calcium-magnesium carbonate in slate associated with the iron formation.

The prevalence of graywacke and arkose in the Upper Huronian series is evidence of immature weathering of the rocks from which they were derived. It has been ascertained by careful calculation[1] that the slates of the Upper Huronian series as a whole are higher

[1] S. H. Davis. The Source of the Upper Huronian group of sediments of the Lake Superior region.
Thesis, University of Wisconsin, 1909.

in feldspar and ferro-magnesian minerals than the average shale and slate showing that the material was not so thoroughly weathered before reaching the sea as the average mud. Perhaps the climate in Upper Huronian times was less favorable to decomposition than in later periods. Furthermore, volcanism was active in sea and on land. Enormous quantities of basaltic lava and ejectamenta were poured forth from fissures and craters and became intercalated with the sediments. Under ordinary atmospheric conditions basalt is rapidly disintegrated and decomposed. Great quantities of basaltic detritus were doubtless carried from the land to the sea in streams to be added to that which was poured forth in the sea to be broken up and worked over by the water. Volcanism was especially vigorous in the Iron River-Crystal Falls-Florence area and its products are widely distributed in the sediments as well as in breccias, tuffs and ellipsoidal flows.

CONDITIONS OF DEPOSITION AND ORIGIN OF THE IRON-FORMATION.

Conditions favorable to the deposition of iron formation were recurrent at intervals throughout the history of the Upper Huronian in the Iron River district. This is shown by the intercalation of iron formation strata at different horizons in the series. The iron formation is associated at different places with every type of rock known in the succession and passes by gradation in different places into all of the other sediments. So far as the purely physiographic factors are concerned it seems that the iron formation was formed under conditions not essentially different from those under which the associated sediments were deposited. It should be borne in mind that the characteristic minerals in the iron formation are abundant in some associated sediments which are classed as slate from which the iron formation differs only in the relative abundance of the essential minerals, viz., soluble silica and iron bearing carbonates or, to put it in another way, iron formation was frequently deposited with the mud and other detritus which forms the bulk of the sediments. At times when iron bearing carbonates and silica were abundant in solution precipitation of these minerals predominated over mechanical sedimentation and thus the iron formations were built up. Conditions for deposition of iron formation were recurrent, oscillating, and often local, as shown by the intercallation of thin

bands of iron formation in slate. The variations in thickness of the different lenses are due in some measure to relative duration of conditions favoring deposition but probably in greater measure to fluctuations in supply of materials. Deposition was rapid in proportion to abundance of materials supplied. The iron formation lenses are to be regarded as a result of an unusually abundant supply of iron formation materials to the sea rather than to cessation of mechanical sedimentation during process of their accumulation.

SOURCES FROM WHICH THE IRON FORMATION WAS DERIVED.

We have now to inquire into the source of the iron formation materials and to explain the sudden influx of these materials contributed to the sea in large quantities at recurrent intervals. If the iron formation is a chemically precipitated rock, as it doubtless is, prior to deposition the silica and iron were in solution in sea water. There are two possible sources from which the sea may have derived its supply of materials. The more obvious of these is the rocks forming the land area which drained into the sea. It is a well known fact that iron is dissolved and carried in solution in both underground and overground run off. However, the amount which is carried today in the surface drainage is negligible except under local bog conditions where the waters are charged with carbonic acid and organic acids from the influence of decaying vegetation. Under ordinary weathering conditions iron is oxidized and remains in place as insoluble oxide or is transported in suspension in water with other insoluble weathered products. Some of the iron doubtless reached the sea in this form but we have no evidence in this district that iron oxide was an important original iron formation mineral.

The thickness and extent of the main iron bearing horizon together with the comparatively unweathered character of the associated sediments compared with the average shale or slate and perhaps the coarseness of grain shown by some of them indicate that the iron was not deposited under the well understood bog conditions of later times. It should be remembered that, (1) there are no known bog deposits comparable with these in thickness and extent, (2) drainage waters competent to bring down great quantities of rather coarse detritus are not those which

would under ordinary conditions carry iron in solution since the ability of the waters to hold soluble iron is dependent on slow movement through well vegetated low areas.

The quantity of iron carried in solution in rivers of today is negligible. In the analyses of the waters of 20 representative American rivers published by Chamberlain and Salisbury[2] traces of ferrous iron are found in only three, the Rio Grande Del Norte, the Ottawa, and the St. Lawrence and traces of ferric iron in but two, the Delaware and Maumee.

From the foregoing it seems that under the physiographic conditions which seem to have pertained only small quantities of iron could have reached the sea in solution in streams if the climatic and atmospheric conditions were similar to those which now prevail. What may have been the composition of the atmosphere in this early period we have as yet no means of knowing, but it seems probable that carbon dioxide was much more abundant in the earlier atmospheres than in those of later times. With the exception of water-vapor carbon dioxide is the most abundant gas emitted from volcanoes. It is abundantly occluded in meteorites and in igneous rocks. Under Chamberlain's planetesimal hypothesis of the earth's origin carbon dioxide was originally abundant in the rocks of the earth's interior whence it was extruded to form in large part the initial atmosphere through processes of volcanism which were dominant in the early periods of the earth's history. It is not unreasonable to suppose that the atmosphere of Upper Huronian times was heavily charged with carbon dioxide, especially as geologic processes involving abstraction of carbon dioxide from the atmosphere have since early times outbalanced those which restore it.[3] An atmosphere heavily charged with carbon dioxide would promote the weathering of rocks and especially the solution and transportation of iron as carbonate. It would also exert a favorable influence on the growth of plants and thus indirectly on rock weathering. In such an atmosphere the chief factors which now prevent the solution and transportation of iron on a large scale in streams would be inoperative.

Any acceptable theory of the origin of the iron formation must account satisfactorily for the source of the silica. That the silica

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[2]Chamberlain, T. C., and Salisbury, R. D. Geology, Vol. I. table opposite p. 106.
[3]See Van Hise, Charles Richard. A treatise on Metamorphism. Monograph 47, United States Geological Survey, p. 974.

was deposited with the iron carbonate cannot be questioned. Through subsequent metamorphism it has been extensively rearranged in some of the rocks, some has been introduced from outside sources and some has been carried out of the formation but in the less altered rocks the even lamination of the chert with iron carbonate leaves no room for doubt that both were deposited together as a sediment. As in the case of iron carbonate, the more obvious source of the silica is the rocks forming the Upper Huronian land areas. Conditions favoring the solution and transportation of iron carbonate would favor solution and transportation of silica. Silica is more easily carried in solution in streams than is iron and is present in sea water from which it has been deposited since early times as chert in association with limestone and dolomite.

From the above we may conclude that under an atmosphere highly charged with carbon dioxide ordinary processes of erosion and transportation would contribute to the sea in soluble form important quantities of iron and silica.

We have now to consider whether the quantities of iron and silica contributed through the operation of the erosional processes discussed in above paragraphs would be an adequate supply under the physiographic conditions attending the deposition of the iron formation.

It will be recalled that the Upper Huronian series throughout has the characteristics of a delta deposit, in any event it was laid down in shallow water of varying depths. The rapid, oscillating, variations in conditions of sedimentation were due mainly to fluctuating supply of sediment. With the exception of non-fragmental sediments, i. e., the iron formation, fluctuating supply is easily accounted for by seasonal and periodic variations in precipitation without making appeal to oscillating earth movements affecting physiographic relations between land and sea. Under any prevailing combination of physiographic and climatic conditions, barring some unusual factor, it is, however, difficult to see why there should have been a greatly fluctuating supply of soluble silica and iron. These materials should have been contributed more or less uniformly throughout the period of sedimentation. If we embrace the assumption that silica and iron in soluble form were uniformly contributed to the sea, we face the question, why did not the precipitation of iron and silica, after having once begun, take

place uniformly and continuously? The readiest answer is, conditions for deposition were more favorable at some times than at others, but this answer is satisfactory only when the favorable conditions for deposition are fully explained. Obviously the most favorable condition for deposition is abundance of materials in solution and certainly great influx from time to time of materials in solution would be a strong factor in determining quantity of material deposited. There are reasons to believé that deposition of the iron formation was coincident with periods of unusual influx of abundant silica and iron as later shown.

It will be recalled that the iron formation is closely associated with black carbonaceous slate and is itself carbonaceous to varying extent. This close association with carbonaceous materials is probably not accidental and we are led to believe that it may have genetic significance. The occurrence of black carbonaceous slate and limestone has been considered strong evidence of the presence of life in the pre-Cambrian seas of the Lake Superior region. An early theory of Van Hise's[4] depends on the presence of carbonaceous matter (presumably organic) in the sea to explain the formation of iron carbonate. If the iron had been precipitated as ferrichydroxide and mixed on the sea bottom with decaying organic matter it would have been reduced to ferrous oxide which by uniting with carbon dioxide would form ferrous carbonate. The deposition of silica in the form of chert is presumed to have taken place through a process analogous to those of later times when extensive beds have been formed through the accumulation of siliceous tests of small organisms.

On the supposition that life was present in the Upper Huronian sea and that the atmosphere was heavily charged with carbon dioxide we may conclude, therefore, that with uniform accessions of iron and silica in solution, iron formation may have been deposited at recurrent intervals when the requisite kind of life, whatever its nature may have been, was unusually abundant. The lense-shaped discontinuous beds represent conditions of local development of these life forms. Under this theory deposition must necessarily have taken place very slowly and almost complete cessation of mechanical sedimentation was necessary to the accumulation of any considerable thickness of iron formation.

[4]Van Hise, Charles R. Monograph 19, United States Geological Survey, pp. 249-50.

While the theory above outlined, under the most favorable interpretation, accounts for the source of materials and the deposition of iron formation it is not an adequate explanation of all the phenomena of constitution, manner of occurrence and lithologic associations of the iron bearing formations of this and adjacent areas. The theory is not inclusive. It does not include all possible sources of iron and silica, does not recognize possible precipitation of iron formation through chemical processes unaided by organic life, does not account for rapid deposition in the face of evidence pointing to rapid accumulation and offers only partial explanation for the absence in post-Cambrian formations of iron bearing beds of similar constitution and equal extent.

The escape from some of these difficulties is afforded in appeal to the instrumentality of aqueo-igneous agencies in supplying iron and silica in solution to the sea and in direct chemical precipitation of both silica and iron to form the iron bearing beds. It has been shown that volcanism was active in this and adjacent areas throughout the Upper Huronian time both in sea and on land. Basic lava flows of submarine origin are abundant and in at least two known areas, viz., in the Atkinson and Jumbo belts, these rocks are closely associated with iron formation. Furthermore, the iron formation of the central area seems to have been laid down contemporaneously with or soon after an outbreak of volcanic activity recorded in the ellipsoidal flows and the volcanic breccias of the southern part of the district. Thus we have evidence that the periods of iron formation deposition were probably contemporaneous with periods of volcanism. The causal effects on iron formation deposition of great extrusions in the sea of hot basic lavas are too complex for satisfactory brief statement but it may be indicated here that iron and silica may have been contributed rapidly and directly to the sea in soluble form through pegmatitic action accompanying these extrusions especially during the cooling stages and also by chemical interaction between the sea water and the hot lavas. Furthermore, the quantity of iron contributed in solution in streams would doubtless be accelerated by reason of the sudden outpourings of hot basic lavas and ejectamenta on the land. Thus may be explained the field association of iron formation with basic extrusives, the coincidence of periods of pronounced volcanic activity and iron formation deposition, and

the apparent rapid deposition of iron formation under shallow water conditions.

This later addition to the theory of origin of the iron formations of the Lake Superior region has been established by Van Hise and Leith.[5] In view of the inadequacy of earlier theories, the writer has indicated the applicability of its basal ideas to the Iron River district in so far as may be inferred from physical relationships of the iron formation to associated rocks. The igneous relationships of iron formation are more clearly indicated in some other districts than in this one, especially in many Keewatin areas.[6]

The results of the investigation of the origin and deposition of iron formation by Van Hise, Leith, and assistants will soon appear in print in a monograph of the United States Geological Survey. In view of this it would not be profitable here to enter further into a discussion of the origin of the iron formation since little advance over present knowledge could be made without attacking the subject on broad lines and making appeal to data afforded only in a broad study of the iron bearing series of the pre-Cambrian rocks of the whole earth.

THE IRON ORES.

CHEMICAL COMPOSITION.

The iron ores are, without exception, medium to low grade, non-Bessemer hematites. The iron content of ores shipped from the different mines in 1909 ranges from 56.67% to 49.87%. In the following tables there are given complete average cargo analyses of Iron River ores for the season of 1909 and the average chemical composition of ores for 1907 with range for each constituent compared with same for the Crystal Falls and Florence districts. The latter was compiled by W. J. Mead and is published by permission of the United States Geological Survey.

[5]Unpublished manuscript.
[6]For description of igneous relationships of iron formation in a typical Keewatin succession in Canada, see Allen, R. C. Iron formation of Woman River area. Ontario Bureau of Mines. Eighteenth report, 1909, pp. 254-62.

COMPLETE AVERAGE CARGO ANALYSIS OF IRON RIVER ORES OF THE SEASON 1909.

Published by the Lake Superior Iron Ore Association.

[*The upper line of figures opposite each ore represents its analysis when dried at 212° F.; the lower line when in its natural condition.*]

Ore.		Iron.	Phos.	Silica.	Mang.	Alumina.	Lime.	Magnesia.	Sulf.	Loss by ignition.	Moist.
Baker	Dried	56.670	.313	7.460	.280	1.470	1.630	.920	.009	5.150	....
	Natural	51.8750	.2860	6.8169	.2558	1.3432	1.4895	.8406	.0082	4.7060	8.620
Baltic (group). Including... Baltic, Caspian, Fogarty	Dried	55.40	.493	7.88	.36	3.08	1.50	1.87	.033	5.01	....
	Natural	49.83	.4435	7.088	3.24	2.770	1.349	1.682	.0297	4.506	10.05
Berkshire	Dried	54.45	.709	8.25	.18	4.23	2.79	2.40	.031	2.45	....
	Natural	48.10	.626	7.29	.16	3.74	2.46	2 12	.027	2.16	11.66
Chatham, including No...	Dried	54.50	.346	9.39	.21	2.73	.79	1.05	.088	6.71	....
	Natural	51.37	.326	8.85	.20	2.57	.74	.99	.083	6.32	5.75
Dober Lump	Dried	55.8258	.6334	5.3536	.3493	....	....	....	....	....	....
	Natural	53.7605	.6100	5.1555	.3364	....	....	....	....	....	3.6996
Hiawatha	Dried	49.87	.35	14.16	.234	4.20	1.30	1.75	.084	....	....
	Natural	46.34	.325	13.15	.217	3.90	1.21	1.63	.078	....	7.08
James	Dried	54.89	.480	9.60	.30	.99	.40	.20	.015	9.02	....
	Natural	50.50	.4416	8.832	.276	.911	.368	.184	.0138	8.298	8.00
Tully	Dried	56.100	.580	8.000	.360	2.200	2.120	1.650	.008	3.200	....
	Natural	50.490	.5220	7.2000	.3240	1.9800	1.9080	1.4850	.0072	2.8800	10.000
Youngs	Dried	56.05	.50	7.60	.16	3.20	.82	.71	.04	5.45	....
	Natural	52.1265	.465	7.068	.1488	2.976	.7626	.6603	.0372	5.0685	7.00

AVERAGE CHEMICAL COMPOSITION OF ORES FROM CARGO ANALYSIS FOR 1907, WITH RANGE FOR EACH CONSTITUENT.

(Ores dried at 212° Fahrenheit.)

	Crystal Falls district.		Iron River district.		Florence district.
	Average.	Range.	Average.	Range.	Average.
Fe	54.10	49.15 to 58.64	55.70	50.25 to 58.10	54.50
P	.437	.103 to 1.000	.396	.277 to .622	.32
SiO_2	6.27	5.62 to 10.00	8.62	4.28 to 19.29	6.72
Mn	1.27	.20 to 5.00	.20	.10 to .30	.26
Al_2O_3	2.94	1.04 to 4.98	2.54	.80 to 4.39	3.35
CaO	2.62	1.43 to 4.24	.92	.33 to 3.06	1.51
MgO	2.15	.30 to 4.09	.76	.16 to 1.82	2.46
S	.056	.030 to .161	.057	.011 to .105	.132
Loss in ignition	5.89	1.11 to 10.40	5.25	1.50 to 9.66	5.20
Moisture	8.46	3.00 to 12.02	8.23	3.19 to 12.00	10.86

MINERAL COMPOSITION.

The ores are mainly soft, red, hydrated hematite, and in subordinate quantity, brown and yellow limonite. The mineral impurities are quartz, some kaolin, calcium and magnesium carbonates, small amounts of carbonaceous matter, and minute amounts of iron sulphide. Manganese in the form of black oxide may occur up to 26% by weight as in the Barrass mine but its presence in amounts greater than a fraction of 1% is exceptional.

Quartz occurs in the form of chert intermixed with iron ore, in small veinlets cutting the ore, and in crystals lining the walls of cavities. In the latter forms it is secondary, in the former it is an unremoved portion of the original chert constituent of the iron formation. In 1909 the silica content of ores shipped ranged from 5.3536% to 14.16%. Kaolin occurs as a weathered product of aluminous impurities in the iron formation. It will be seen by reference to cargo analyses that lime and magnesia contents rise and fall together but either may be in excess, indicating that lime and magnesia are largely combined in the form of dolomite. Calcite occurs in crystal form on the walls of cavities, and the occurrence of magnesite is probable although this mineral was not seen by the writer. Carbon occurs in the form of graphite. Illustrations of the gradation of iron ore into highly graphitic rocks

are given on pp. 81-82. Iron sulphide is rarely present in conspicuous amounts. It is occasionally present in the form of minute veinlets. In the old Sheridan mine it is reported that iron sulphide is so abundant at a depth of about 200 feet as to render the ore worthless. With this exception there is no evidence to show that the content of iron sulphide increases in depth. Magnetite is not known to occur in the Iron River ores although it is present in some parts of the Vulcan formation.

For the most part the ores are moderately hydrated, passing locally and in varying degree in different deposits into more highly hydrated varieties which may be termed "limonitic." The "limonitic" ores differ from the hematites only in having a higher percentage of combined water but not necessarily in proportion to form the mineral limonite ($H_2O = 14.5\%$). In the limonitic ores doubtless there occur the whole series of hydrated oxides from turgite ($H_2O = 5.3\%$) through göethite ($H_2O = 10.1$) to limonite and possibly xanthosiderite ($H_2O = 18.4\%$) but average cargo analyses indicate that of these the lower hydrated varieties are much more abundant.

The color of the ore depends to large extent on the combined water content. The slightly hydrated hematites are dark blue, as in the Dober lump ore, while the more highly hydrated varieties are red to brown and yellow. All of the variously hydrated ores may be associated in the same deposit, in fact they usually are, but some deposits are characterized by an average relatively low or relatively high combined water content. In a given deposit more hydrated ores may follow layers or bands which are separated by others of less hydrated variety. The degree of hydration may also vary irregularly in the deposit. There are no available data to indicate whether the tops of the deposits are more highly hydrated than the bottoms.

PHYSICAL CHARACTERS.

Taking the district as a whole the ores may be graded as medium soft hematite. The less highly hydrated ores are usually but not invariably harder than the limonitic ores. In some mines a hard blue hematite is found. This ore runs higher in iron than the softer varieties. At the Dober mine it is separated in handling from the softer varieties and graded as "Dober lump ore." The hard blue ore breaks out in large fragments which may be readily

crushed to a mixture of small hard blocks and soft ore. Hard stalactitic, botryoidal, and mammillary forms are common on the walls of cavities.

The banding of the ferruginous cherts is often retained in the ores, especially in the highly siliceous varieties which may be regarded as enriched iron formation. As the process of concentration continues, by abstraction of silica and replacement of silica with iron oxide, the banding becomes faint and indistinct and frequently disappears. In those cases where, prior to concentration of the ores, the iron formation has been brecciated the banding in the broken and displaced fragments may be preserved in the ore. In ore where concentraction seems to have been effected mainly by leaching of silica the banding in the iron formation is more likely to be preserved than in ore showing in abundance of cavities lined with botryoidal and mammillary forms that iron has been dissolved and extensively rearranged in process of concentration. Much of the hard lump ore is of the latter variety.

On the whole the ores are very porous. As calculated by Mead the pore space ranges from 5% to 40% of volume, and the volume of a ton of ore varies between 8.5 to 15 cubic feet with an average of about 11 cubic feet.

THE ORE DEPOSITS.

SHAPE AND STRUCTURE.

The shapes of the ore bodies are determined by (1) the general steep dip of the iron formation, (2) thickness of the iron formation, (3) minor structural features such as brecciation, minor folding, banding, jointing, etc. Of these the first and second factors are decidedly the most important in determining the shapes of the ore bodies. The iron formation is in most places vertical or highly inclined and enclosed in walls of slate. Examining the ore bodies from the three dimensional view point, the two components in the direction of bedding are much greater than the transverse component, i. e., normal to the bedding. Even if the ore body extends from wall to wall transversely across the iron formation, a maximum distance of perhaps 300 feet, as for instance in the Caspian mine, the other two components are sufficiently greater to give the ore body a *tabular* shape. Some of the ore bodies follow foot wall slates and grade transversely across the bedding into

ferruginous chert thus being thinner than the iron formation in which they occur. Such gradation also takes place laterally along the bedding. The Berkshire is a good example of this type of deposit. If the iron formation contains *interbedded* slate layers one or more of these may function as a foot wall slate, in which case there may be two or even more ore bodies lying one above the other as for instance in the Fogarty, Youngs, and Riverton mines. But the ore bodies are not invariably related to slate walls. They may occur in the body of the iron formation separated from foot and hanging walls by ferruginous chert, as in Chatam No. 1 mine and to large extent in the Hiawatha mine. If the bedding has not been much broken and disarranged by brecciation the ores follow the banding in the iron formation and the shapes of the ore bodies are essentially the same as those which follow slate walls. If the iron formation is shattered and brecciated with destruction of all parallel structures the ore bodies are apt to be of various irregular shapes and sizes varying from the smallest "pockets" of a few tons of ore up to bodies containing thousands of tons. This type of occurrence is best illustrated in the Baker mine as shown by the workings in the fall of 1909. These ore bodies are not related to slate walls or major structural features of the iron formation. They are irregular concentrations of ore in ferruginous chert into which they grade by decrease in iron and corresponding increase in silica. Their extreme irregularity of shape, size, and manner of occurrence is of course reflected in high mining costs. The occurrence of "ore pockets" is, however, not by any means confined to highly brecciated, large masses of ferruginous chert. They may occur in minor folds of slate or in local brecciated masses associated with minor folds in the iron formation. Relatively large minor folds may affect the shape of an ore body of considerable size as in some parts of the James mine (fig. 14). But the *tabular ore body* standing in inclined position, usually very steeply inclined, with the two greater dimensions in the plane of bedding of the iron formation is the type deposit of the district.

RELATIONS TO WALL ROCKS.

The relations of the ore bodies to wall rocks have been referred to repeatedly in preceding pages. A brief summary of these relations follows.

The ore bodies very commonly lie on relatively impervious slate foot walls. In many cases the foot wall slate is of the black graphitic variety. The foot wall slate is in some instances basal to the iron formation, in others it lies within the iron formation. In some instances the ore body is limited by slate on both foot and hanging walls, either or both of which may lie within the iron formation. The wall slates may in places assume the characters of ferruginous graywacke (reported from the Chicagon mine) or quartz-chlorite-schist as in the Riverton mine.

A common type of ore body is bounded on all sides by iron formation rocks, viz., ferruginous chert and slate.

Lateral gradations to black slate (Dober) and ferruginous graywacke (Riverton and Chicagon) are known.

At Atkinson iron ore is closely associated with volcanic greenstone and also in the Jumbo belt east of Saunders.

Thus the ore bodies are in juxtaposition in different places to nearly all the rocks with which the iron formation is associated.

DEPTH TO WHICH ORE OCCURS.

Many of the ore bodies, in fact nearly all of the larger ones, are exposed at the rock surface. All of the older mines started to mine by the open pit method. Those deposits which are not exposed at the rock surface are connected with this surface by lean ore or ferruginous chert or slate. In no case is an ore body known to be cut off from the surface by intervening iron formation rocks which have not been altered by katamorphism, that is to say, by processes which if completed would result in ore concentration. This is a fact of fundamental significance to the accepted theory of the concentration of the ores and has a practical bearing on exploration which will be discussed later. To date ore has not been mined at depths greater than 700 feet. The Dober and Hiawatha mines are operating on the lower levels at between 600 and 700 feet. Ore is known to occur in both these properties at greater depths. In a vertical drill hole on the Michaels exploration 100 feet south of the center of Section 29, T. 43 N., R. 34 W., ore running above 50% in iron was encountered between 1,360 and 1,712 feet. The bottom of the hole is reported to be in ore. Subtracting depth of overburden, 230 feet, we have 1,482 feet as the

greatest depth below rock surface at which ore is known to occur in this district.

Speculation as to the ultimate depth of mining is hazardous. Large deposits of rich ore occur on the Gogebic range below 2,000 feet. Ore concentration is limited by the depth to which a vigorous circulation of oxidizing waters may penetrate from the surface but theoretical calculations of such depth are invalidated by the uncertainty of factors involved. No reasons are known why ore should not occur here at depths as great as in other districts of the Lake Superior region. Past experience in exploration and known favorable structural conditions invite to exploration at depths greater than those now attained.

TOPOGRAPHIC RELATIONS.

In considering the relation of the ore bodies to hills and valleys it should be borne in mind that the present topographic forms bear only slight relation to those which existed in post Huronian and pre-Ordovician time. It was during this time that the ores were mainly formed. If there is any significant relation between ore deposits and topographic forms such can be discerned only in reference to the pre-Ordovician erosion surface and not to the present surface. Except in those cases where the covering of glacial drift only partially masks the character of the underlying rock surface any observed relationships between ore bodies and hills and valleys as they exist today are purely accidental and have no significance. This will be made clear in the following brief outline of the post-Huronian physical history of the district.

At the close of the Upper Huronian period of sedimentation the bottom of the sea became land and thence to Middle Ordovician time, so far as we have evidence, this district was not again submerged but remained part of a land area which was subject to the processes of erosion which are in operation on the land areas of today. Accompanying the withdrawal of the sea, and probably the cause of its retreat, the area was uplifted and the rocks were folded into anticlines and synclines. It is not probable that all nor perhaps the major part of the folding in the Upper Huronian series was accomplished at this time. In the Gogebic range to the west the main deformation took place in post Keewenawan times but is is certain that long before the Middle Ordovician sub-

mergence the Upper Huronian rocks had been folded as we now see them and had been eroded for long ages with the removal of many hundreds and perhaps thousands of feet of strata. As the plane of erosion worked downward the folds were truncated, exposing at the surface the upturned edges of the iron formation and other rocks in belts of curving and sinuous form. During this long period of erosion the ores were mainly formed as shown in the Menominee district on the east where iron ore is found in the conglomerate at the base of the Cambrian sandstone in such relations as to show that the ore had been formed prior to the Cambrian submergence. The Paleozoic sea did not cover this area until Middle Ordovician time. The Cambrian formations of the Menominee district and the Ordovician formations of this district are about flat lying and undeformed. In both districts the Paleozoic seas advanced over a rugged, hilly country. The valleys were first filled with sediment and gradually even the tops of the hills were buried. The covering of Paleozoic rocks put an end, or at least a great check, to the formation of iron ores. When the Paleozoic sea finally withdrew the area was again subject to erosion. Streams were formed and began the work of removing the flat lying limestone and sandstone. The pre-Cambrian rocks are much harder and more resistant to erosion than the Paleozoic rocks. Wherever these rocks were uncovered in the valleys the streams were shifted to the softer rocks after a well known principle of erosion under which streams tend to follow lines of least erosive resistance. As erosion went on the pre-Cambrian topography was uncovered and the streams finally adjusted themselves to the old valleys which they found ready made in the harder rocks. The topography of the rock surface is thus of pre-Ordovician origin modified only by erosion since the mantle of Paleozoic rocks was removed. As the Huronian series were uncovered the conditions for ore concentration here were gradually re-established and ore concentration has continued without interruption to the present day if we except locally the retarding effect of a glacial cover in some places above 300 feet thick. The process of ore concentration is an extremely slow one, so slow in fact that the part which has been accomplished since glacial times is insignificantly small.

It is now clear that we must examine the pre-Ordovician rock surface for significant relationships between ore deposits and topo-

graphic forms. This should be emphasized here for the reason that many prospectors look with favor on a "draw" or a swamp as a promising locality for exploration. In fact it was largely the success attending exploration in the vicinity of the Baker mine that induced to further exploration up the Baker "draw" resulting in discoveries of ore as far northeast as the S. W. ¼ of the S. W. ¼ of Section 21, T. 43 N., R. 34 W. Another "draw" which has attracted some attention extends north of east through the James mine property. This small valley is crossed by the James and Konwinski belts of iron formation. In the former case Baker Creek seems to follow in a general way a deep pre-glacial valley which doubtless carried the bed of a pre-glacial stream flowing northeast while in the latter case the "draw" or valley is entirely in drift and has no relation to the topography of the underlying rock surface. In the former case it may be that the ancient stream bed followed in a general way the strike of an iron formation belt which formed the north side of its valley, since drill holes in iron formation are thus far all on the north side of the depression. The two illustrations above given emphasize the importance of the exercise of discrimination and care in the application of a well founded principle of exploration.

On the general map of the district (Plate 1) the general outlines of the topography of the rock surface in the producing part of the district are indicated to the extent of known data. It cannot be expected that results based on inaccurate data can be more than approximately correct. The contours in green have been drawn from data furnished by several hundred drill holes, rock exposures, shafts and pits, and a small scale topographic sheet. It will be seen by reference to this map that the ore bodies show a decided preference for valleys and hill slopes rather than upland areas. With the exception of the deposits on the James belt every producing deposit in the district is either in a valley or under a decided slope. The same relation seems to hold in large measure for occurrences of ore known only from drill records. The great Caspian deposit lies in the bottom of an ancient drainage course trending northeast through the Baker property and carrying the ore of Sections 29 and 31 in T. 43 N., R. 35 W. The relations of the Berkshire, Fogarty, Youngs, and Baltic deposits to high ground on the east are seen at a glance. From the Caspian to the old Beta mine a

depression followed by the Iron River carries the Dober, Isabella, Hiawatha, Chatam and Riverton mines.

To what extent the location of ore bodies in valleys and under decided slopes is a matter of pure accident and to what extent is governed by natural laws is difficult to determine. That the ores have been secondarily concentrated by oxidizing meteoric waters has not recently been seriously questioned. Obviously those parts of the iron formation most happily situated to receive a vigorous circulation of oxidizing waters are more apt to carry ore deposits than those parts not so situated. In general, such locations are to be found along natural drainage lines and under hill slopes, and it is safe to assume that, barring adverse structural conditions, ore deposits are more apt to be formed in these places than elsewhere.

CONCENTRATION OF THE ORES.

The processes involved in the concentration of the ore deposits in the Lake Superior region were early discerned by Van Hise in his studies of the Penokee-Gogebic iron range and fully discussed by him in 1892.[7] The principles of iron ore concentration laid down by Van Hise for the Penokee-Gogebic range have been found to have general application in the Lake Superior region with such modifications and additions as are demanded by the varying structural conditions in the different areas. The discussion which follows is mainly an application of these now well known principles to the concentration of iron ores in the Iron River district.

At the close of Michigamme (Upper Huronian) time this and adjacent areas were uplifted, the ocean receded and the rocks were exposed to erosion. There is evidence in the schistose character of the slates and graywackes in many parts of the district and the folding without fracture in some parts of the iron formation that the rocks now exposed at the surface were deformed under a considerable thickness of strata which has since been removed by erosion. During deformation under load the iron formation underwent a more or less complete recrystallization. It is not possible to conceive that the brittle layers of cherty iron carbonate could be bent and contorted without breaking except through internal molecular rearrangement in the mineral constituents. In different places the iron formation was deformed mainly by brecciation, by

[7]Van Hise, C. R., and Irving, R. D. The Penokee Iron Bearing Series of Michigan and Wisconsin, Monograph 19. United States Geological Survey.

folding combined with brecciation, and by folding unaccompanied by prominent brecciation. The conditions of deformation varied from place to place from those of the zone of flow to those of the zone of combined fracture and flow depending perhaps on the variations in the intensity and rapidity of application of the deforming forces. It is certain that the deformation was a slow process and that the intensity of deformation was variable in time as well as place. There was also doubtless more than one period of general deformation. A rock which was earlier folded in the zone of flow may have been brecciated at a later period in the zone of fracture due to removal of load by erosion of overlying rocks. Under any conditions the iron formation would respond less readily to anamorphic changes in mineralogical composition than the associated sediments of more complex constitution. Locally, as for instance on Stambaugh hill, the effects of anamorphism are seen in the development of magnetitic slates but on the whole the iron formation was not mineralogically altered where folded in the zone of flow.

The iron formation was folded prior to the concentration of the ores which was inaugurated only after the folds had been truncated by erosion exposing the iron formation at the surface. That this is true is shown beyond the shadow of a doubt by the relations of the ore bodies, (1) to the surface, (2) to structural features such as folds, breccias, and joints, (3) to natural channels of downward underground circulation.

(1) It has already been shown that all of the ore bodies connect with the surface either directly or indirectly through ferruginous chert or slate which for present purposes may be considered as lean ore. It is equally true that the ore bodies do not extend downward indefinitely but are limited to a relatively shallow depth. It has been shown by drilling that the vertical range of the zone of oxidation varies greatly up to above 1,712 feet. Unoxidized, cherty iron carbonate rocks are frequently found in drilling at depths of less than a hundred feet from the rock surface and less often at only a few feet. Explorers have been taught by experience, entirely aside from reasoning based on theoretical grounds, that ore deposits are not found under a cover of unweathered iron formation rocks and when such rocks are encountered in drilling work is usually discontinued. Of course there are cases where a considerable thickness of unaltered iron for-

mation may lie beneath a protecting impervious slate cover and it is customary to drill to sufficient depths to make sure that the limit of the zone of oxidation has been reached in the direction in which the hole is pointed. The irregularity in depths to which oxidation has extended is illustrated in fig. 16, which is a section constructed from borings made by Mr. Wm. Connibear for the Cleveland Cliffs Iron Co.

It has been shown that the ores were not originally deposited as oxide but as ferrous carbonate which was subsequently altered to ferric oxide. Oxidation is one of the characteristic reactions of the belt of weathering, less conspicuously of the belt of cementation, and with one or two unimportant exceptions does not take place under deep seated conditions.

In the light of the above considerations it is certainly more logical to believe that the ores were formed in *consequence* of the descent of the zone of oxidation on the original ferrous carbonate rocks as the overlying strata were removed than to assume that the ores had been formed under deep seated conditions and later simply exposed at the surface by erosion.

(2) That the relation of the erosion surface to the ore bodies is a causative and not an accidental one becomes more strongly apparent from a study of the relations of the ore bodies to structural features in the iron formation forming natural trunk channels of underground circulation of waters descending from the surface. Where the iron formation is in practically vertical position the ores may not show decided preference for bounding slate walls but may occur in lenses and bands anywhere in the formation or may occupy the width of the formation from wall to wall but where the rocks are inclined the ore bodies show decided preference for impervious slate foot walls and, wherever they occur, for pitching troughs. The ores are also characteristically associated with brecciated parts of the iron formation. The selective preference of ore bodies for these structural features indicates that the structures antedate the ores, and have exercised a causative influence on ore concentration. On no other assumption can the observed relations be explained.

(3) If the iron ores have been formed from an original cherty iron carbonate by oxidation of the ferrous iron and removal of silica, the only known agency competent to effect the alteration is that

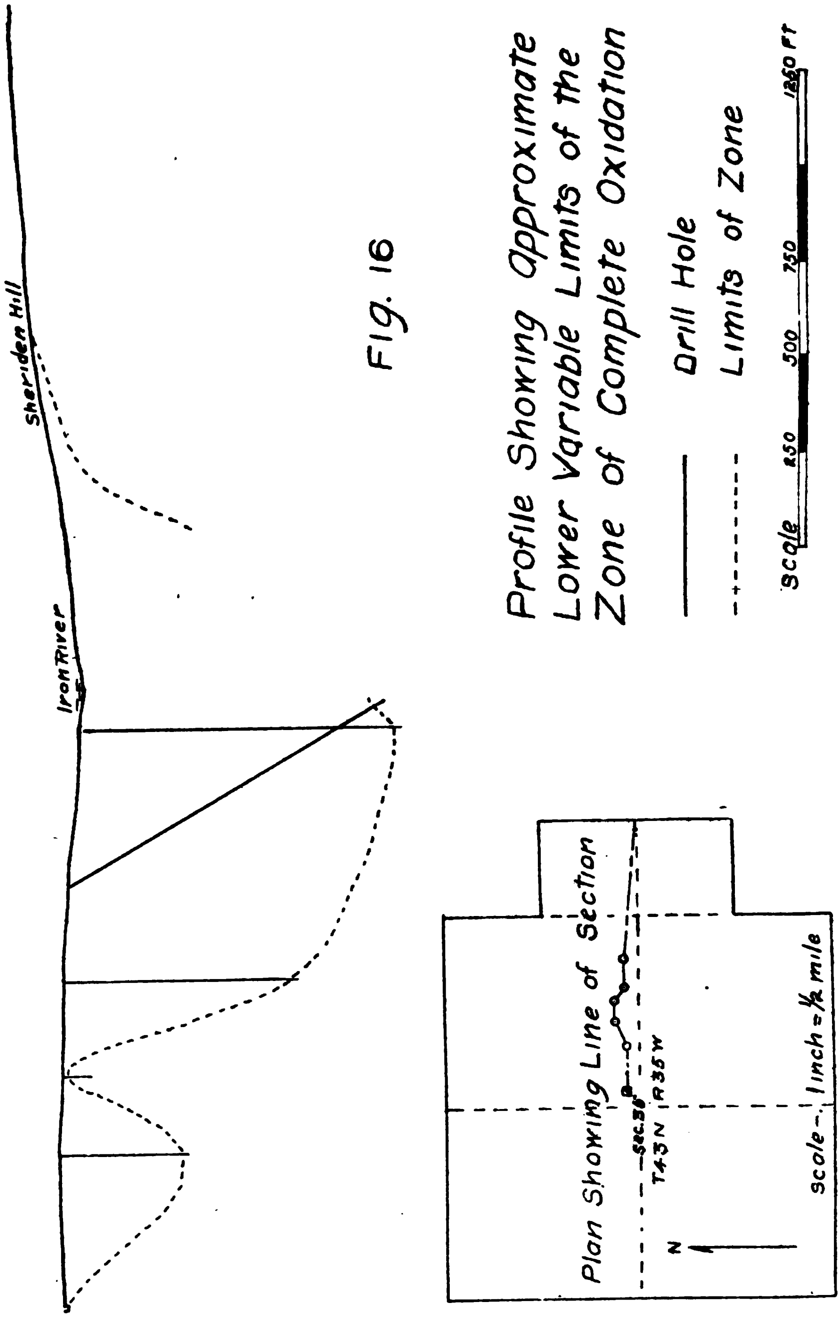


Fig. 16

Profile Showing Approximate Lower Variable Limits of the Zone of Complete Oxidation

of circulating aqueous solutions. The occurrence of ore on footwalls rather than under hanging walls, and in pitching troughs rather than under pitching arches, is evidence that concentration was effected not by waters *rising* from depths but by waters *descending* from the surface. Meteoric waters descending from the surface carry abundant oxygen while those rising from depths are characteristically reducing.

Starting with the basal premises (1) that the deformation of the iron formation preceded the concentration of the ores, (2) that ore concentration followed the truncation and exposure at the surface by erosion of the folded iron formation, (3) and that concentration was effected by downward-moving, meteroic, oxidizing waters, we have now to consider briefly in sequence the various physical and chemical agencies which resulted in the formation of the ore bodies in their present positions.

Meteoric waters enter from the surface by innumerable openings in the rocks. In the iron formation these openings are afforded by fracture and bedding planes and minute pore spaces. Of the water which enters the rocks some reappears at the surface in springs and as seepage on the land and under streams and water bodies while the remainder is returned directly to the atmosphere by evaporation from the surface, capillary action in the rocks combined with evaporation, and through exhalation and evaporation from plants. Most of the water which is returned to the surface by capillarity, evaporation, and plant action has not penetrated far from the surface and its effect on ore concentration is therefore negligible.

It is obvious that the movement of water descending from the surface to join the underground circulation and to finally reappear at the surface has a downward and a lateral component and in the majority of cases an upward component. Having shown that concentration of the ores has been effected by downward moving waters it will be necessary for present purposes to consider only the downward component including therein downward lateral movement.[8]

It has been shown that the alteration of cherty iron carbonate

[8]For full treatise on movements of ground water see Slichter, C. S. "Theoretical Investigation of the Motion of Ground Water," 19th Ann. Report U. S. Geol. Survey, 1897-98, pt. No. 2, and Water Supply and Irrigation Papers No. 67. For general application of movements of underground water to ore deposition, see Van Hise, Chas. R., Some Principles Controlling the Deposition of Ores. Genesis of Ore Deposits, A. I. M. E. 1901, pp. 282-432.

to iron ore involves oxidation of the ferrous carbonate and removal of silica. Waters entering the iron formation at the surface carry oxygen and carbon dioxide in solution. The oxidation of the iron carbonate takes place under the following reaction,

$$4FeCO_3 + 3H_2O + 2O = 2Fe_2O_3 + 3H_2O + 4CO_2,$$

with production of hematite and carbon dioxide. Hematite is insoluble in oxidizing solutions and is thrown down at the place where the reaction occurs. Waters bearing carbon dioxide take iron carbonate into solution. It will be noted that the reaction producing hematite sets free carbon dioxide which is added to waters from the surface bearing carbon dioxide derived from the atmosphere thus increasing their solvent effect on iron carbonate. It is therefore evident that some of the iron carbonate was taken into solution and carried downward. Precipitation of iron carbonate from solution as iron oxide would occur in places where the solutions become strongly oxidizing. This may have occurred by intermingling of waters bearing iron carbonate in solution with waters which were oxidizing by reason of having come more directly from the surface or having traveled more rapidly through open channels or through rocks in which oxidation had been earlier effected.

It is well known that silica is soluble to some extent in pure water but it is much more readily soluble in waters bearing carbon dioxide. In so far as organic acids were carried downward from the surface they would aid in the solution of silica. Silica which was taken into solution was carried downward thus enriching the iron formation by its abstraction. It is evident that oxidation of iron carbonate and solution of silica would take place at the surface and continue downward to the limits of the circulation of oxidized and carbonated waters.

The downward movement of water in the iron formation is affected, (1) by the attitude of the beds, vertical or inclined, (2) by the character of the openings in the rocks, (3) by occurrence of slate layers in the iron formation, below it or above it (4) by the folding, producing pitching troughs and breccias, and (5) by the effective head.

(1) If the iron formation be in vertical position the waters move downward along available openings such as joints and bedding planes but do not show tendency to localization in any particular

horizon unless such horizon is generally more porous, jointed, or brecciated. The influence of the bedding planes on movement of water is illustrated in ore deposits bounded by planes parallel to the bedding in middle horizons of the iron formation and also in alterations often occurring along joints and bedding planes while at slight distances from these openings the rock remains unaltered or only slightly altered.

(2) Where the iron formation is much fractured and brecciated, offering easy passage for downward moving waters, the conditions for ore concentration are more favorable than in those parts of the formation not thus affected. The preference of ore bodies for brecciated parts of the iron formation has already been illustrated.

(3) If the iron formation be in inclined position, downward circulation is concentrated on such impervious slate beds as may occur in the formation or directly below it. The water moves vertically downward, except as deflected along bedding planes, until an impervious slate layer is encountered on which it is concentrated and moves downward along the dip. The occurrence of ore bodies on slate footwalls is illustrated in most of the mines of the district, notably in the Youngs, Fogarty, Berkshire, Riverton, and James.

(4) Pitching troughs in slate or other relatively impervious rocks would obviously afford the most favorable conditions for concentration of downward moving waters. Such troughs are of common occurrence but unless of large dimensions their effect on ore concentration is often obscured by the extention of ores across the accompanying arches. (See fig. 14.)

The process of ore concentration by downward moving meteoric water is beautifully illustrated in miniature in the James mine. In the fall of 1908 a stream of water carrying perhaps 20 to 25 gallons per minute issued from an opening in the trough of a small, tightly compressed syncline of ferruginous chert plunging S. E. into the main drift on the third level. The trough of the syncline adjacent to the water channel was completely altered to high grade ore which became leaner away from the opening and passed gradually into ferruginous chert. This phenomenon is a perfect illustration on a small scale of the concentration of ore in a pitching trough. (Fig. 17.)

(5) The downward extention of ore is limited to the depth to

which an active circulation of oxidizing waters may penetrate. Meteoric water which is returned to the surface in flowing springs or as seepage has somewhere entered the rocks at an altitude which is higher than the point of escape. The difference in altitude between the points of entry and escape is the *head*. The effective head is the difference in altitude between the point of escape (which is at ground water level) and the level of ground water beneath the catchment area, and the *force* which produces circulation of water at depths below the points of escape is the pressure exerted by a column of water whose length is the effective head. The movements of ground waters are complex but it has been shown by Slichter that ground water in moving under head from place to

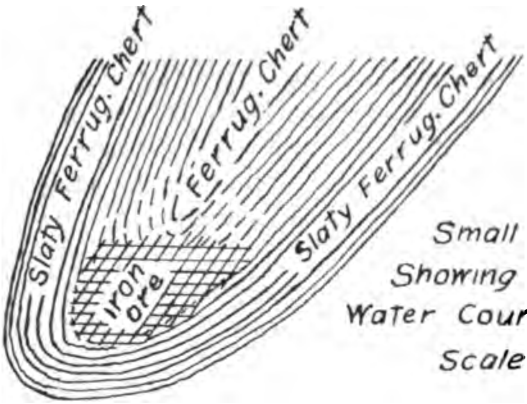


Fig. 17

Small Fold in James Mine Showing Influence of Local Water Course on Ore Concentration
Scale— 1 inch = 2½ Feet

place through the rocks utilizes the entire available cross section and under favorable conditions, i. e., if the rocks contain continuous openings through which the water may freely pass, a slight head is sufficient to cause circulation at great depths. Under any conditions the circulation will be active at depths in proportion to effective head, and oxidizing waters coming from the surface will be more apt to carry oxygen to great depths in an active circulation than in a sluggish one. The effective head in the Iron River district at the present time is inconsiderable, in the producing area being nowhere above 200 feet. Ore occurs at depth of approximately 150 feet below sea level and probably at still greater depths. The ground water level is near the surface and though there is no way of making satisfactory calculation it has been

questioned that active circulation of oxidizing water under slight head pertains at such depths below ground water level as are reached by the ore bodies. However, bearing in mind that oxidation proceeds from the surface downward it is evident that water will retain its oxygen content to gradually increasing depths as oxidation is effected in the rocks at higher levels and that in time oxidizing waters may penetrate to great depths. Furthermore, the change from ferrous carbonate to limonite involves a reduction in volume of 18.22% and to hematite 49.11%[10], consequently, as oxidation progresses the iron formation is made more porous; the ores are more porous than ferruginous chert and unaltered iron formation, therefore, as alteration progresses the descending waters are able to retain their oxygen content to increasingly greater depths by reason of the oxidation previously effected in the rocks at higher levels and by reason of the greater porosity of the altered rocks offering the means of easier and more rapid movement through them.

It is certain that in past times this area exhibited greater surface relief and stood much higher above sea level than it does now. There is evidence in the occurrence of schistose rocks at the surface and the truncation of folds that great thicknesses of strata have been removed by erosion. This is also indicated in the occurrence of ore bodies at the surface. If the ore bodies which are now exposed at the surface have been concentrated by downward moving waters it is evident that much of the iron must have been carried downward from rocks which have since been cut away by erosion for the reason that the increase in porosity of the ores over the porosity of the original iron bearing rocks and allowances for slight slump in the ore bodies only partially accounts for the space occupied by the silica which has been leached out of the original rocks in the process of ore concentration. In so far as the surface was elevated and deeply furrowed by valleys the depth of active circulation of ground water would be great. As the surface of the land was lowered the ore deposits that had been formed would suffer by erosion at the surface and doubtless large quantities of ore have been removed in this way. That ore bodies exist today is proof that downward concentration has in the end kept pace with removal of ore at the surface by erosion.

[10]Van Hise, C. R. A treatise on metamorphism. Mon. 47 U. S. Geological Survey. p. 391.

EXPLORATION.

So far as known the occurrence of ore bodies is limited to the Upper-Middle Huronian formations. The Saunders (Lower Huronian) formation has been prospected to some extent but the results have been uniformly negative. The Lower Huronian is not known to bear ore elsewhere in the Lake Superior region and we have as yet no reason to believe that it is ore bearing in the Iron River district. The writer has drawn the approximate north limit of the Saunders formation on the map. (Plate 1.) North of the Saunders formation the possibility of the occurrence of ore bearing iron formation can be excluded only in those areas which have been proved barren by adequate exploration and in those where exposures are abundant enough to disclose the barrenness of the underlying rocks. All other territory must be *deemed explorable ground.* Of course it is certain that only a small fraction of the unexplored territory is underlain by iron formation.

Where information is entirely wanting it is necessary to begin exploratory work blindly. This, however, is seldom done by conservative and well advised interests. Exploration usually begins on areas adjacent to known occurrences, usually on the strike or the inferred strike of known iron formation. In this manner the known iron formation belts are gradually traced into virgin ground.

No other district in the Lake Superior region presents greater difficulties in the way of exploration. The iron bearing rocks seldom outcrop; they are not magnetic; the overburden varies up to above 300 feet in thickness; the iron formation is usually steeply dipping and its surface width is therefore often not much greater than the thickness; the iron formation is not stratigraphically related to any rock which by retention of uniform characters over large areas can be used as a key to structure and distribution. Under these conditions it is not possible for any one to predict the presence or absence of iron formation in virgin territory very far in advance of actual exploration. The elimination of barren areas is accomplished only by "testing ledge" in a sufficient number of places to demonstrate the absence of iron formation.

The element of chance enters largely into the problems of exploration in any iron bearing district but in the Iron River area perhaps more largely than in any other known Michigan range.

OPEN PIT OF THE RIVERTON MINE. LOOKING NORTH.

(A) CASPIAN MINE.

(B) STOCK PILE AT BALTIC NO. 1 SHAFT IN 1908. LOOKING SOUTH.

(A) STOCK PILE AND SHAFT OF THE YOUNGS MINE IN SEPTEMBER, 1908.

(B) BALTIC NO. 2 SHAFT. LOOKING NORTHWEST FROM THE ZIMMERMAN MINE.

NO. 1 SHAFT AND OPEN PIT OF THE DOBER MINE.

UNDERGROUND IN THE BALTIC MINE.

FOGARTY MINE. LOOKING NORTH TO STAMBAUGH HILL. CASPIAN MINE IN THE DISTANCE.

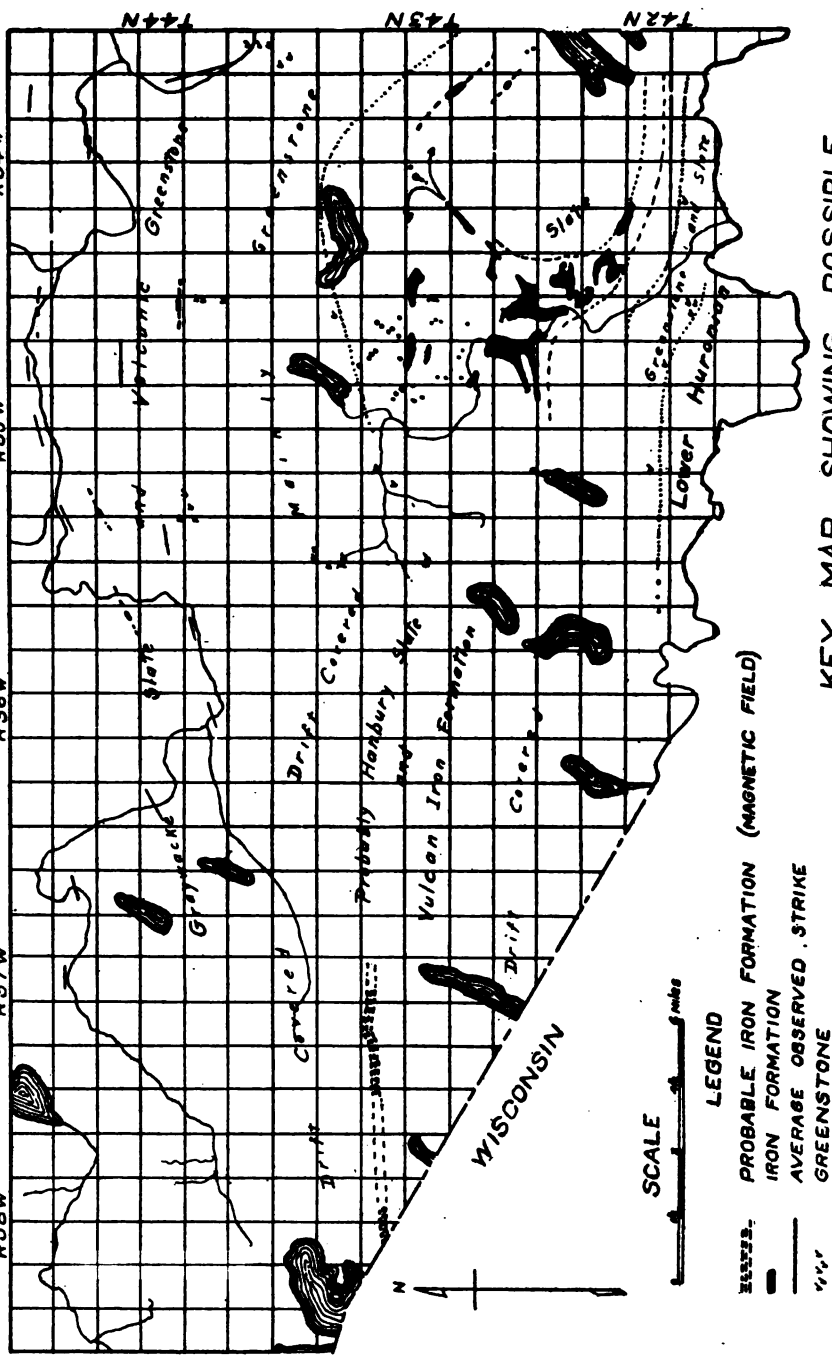
CHATAM MINE. NO. 2 SHAFT. LOOKING ACROSS VALLEY OF IRON RIVER. CHATAM NO. 1 IN THE BACKGROUND.

STEEL HEAD FRAME AT NO. 2 SHAFT OF THE JAMES MINE.

The writer will doubtless be criticized by persons not familiar with the district for not attempting to indicate on the map probable extentions of the known iron formation belts but it is believed that the map is fully as useful in its present form as it would be had such attempt been made. The facts of geology are plainly shown and will readily suggest to the experienced prospector the more favorable areas for exploration. However, in figure 18 possible extentions of known iron formation belts are indicated to the extent that is warranted by available data.

In beginning exploration the prospector usually confines his efforts to "testing ledge" until the iron formation is located. The methods used depend largely on the thickness of the overburden. If the drift is thin the rock may be reached by test pitting but if the level of ground water is reached before "ledge" is encountered a stand pipe from 2½ to 3 inches in diameter is driven from the bottom of the pit. Frequently the stand pipe is driven from the surface. The pipe may be driven with a striking hammer operated by hand or steam power. A churn bit is operated inside the pipe. If boulders are encountered it is necessary to break them up by blasting; in case many boulders are encountered it is usually cheapest in the end to pull the pipe and begin sinking in a new location. When "ledge" is encountered a drill hole is started. Shallow holes may be put down with a churn bit, but in deeper drilling and in angle holes a diamond bit is used.

The ore deposits are associated with ferruginous chert and slate, i. e., with the altered phases of the iron formation. In general, exploration should be confined to the portions of the iron formation thus altered. Experience has shown that ore bodies are not found under any considerable thickness of unaltered iron formation. A drill hole which encounters cherty iron carbonate near the surface or after having penetrated ore or ferruginous slate or chert should be discontinued. Of course instances may be cited where ore or highly altered iron formation has been found *under* practically unaltered cherty iron carbonate but it should be borne in mind that *alteration proceeds from the surface downward* and in the end it is cheapest to "test ledge" until the altered phases of the iron formation are located at the surface. Deep drilling in unaltered cherty iron carbonate has given uniformly negative results. On the other hand deep drilling in ferruginous chert is



KEY MAP SHOWING POSSIBLE EXTENTIONS OF KNOW IRON FORMATION

FIG. 18

warranted by experience. Ore bodies may occur anywhere in ferruginous chert and it is generally wise to push a drill hole where possible to the limit of the zone of complete oxidation in the direction in which the hole is pointed. If slate is encountered below ferruginous chert or ore the hole should be sunk in it to a depth great enough to make sure that the slate is not merely a layer in the iron formation but is basal to it.

Mining engineers and explorers in general are divided in opinion as to the best methods of prospecting for ore bodies after the iron formation has been located by drilling or "testing ledge." Some favor drilling while others prefer underground work. Whether the one or the other of these methods is followed in a given instance is controlled largely by local conditions. If the overburden is deep the sinking of a shaft is often a difficult and expensive undertaking and is not often done unless ore has been previously located by drilling.

Practically all of the mines are operated under lease. The royalties range from 10 cents to 50 cents per ton of ore shipped. The lower figure is paid by two of the older mines, the latter is reported to have been stipulated in a recent lease on a developed property. During 1909 options to explore in virgin ground were freely given on royalties ranging from 20 to 35 cents.

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